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Concentrations and Concentration Factors of Several Anthropogenic and Natural Radionuclides in Marine Vertebrates and Invertebrates

Lawrence Livermore National Lab., CA

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Literature is reviewed and summarized with regard to concentrations of several anthropogenic and natural radionuclides in biological organisms from marine environments. Reported concentration factors for these radionuclides in organisms are tabulated for marine fish and invertebrates from water masses affected by different source terms.

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CONTENTS

Abstract 2
Introduction 2
Acknowledgements 4
Annotated Bibliography 5
Plutonium and ^{241}Am Concentrations in Marine Fish from Regions of the Pacific Ocean 5
Plutonium and ^{241}Am Concentrations in Marine Fish from Regions of the Atlantic and Indian Oceans and Mediterranean Sea 11
Plutonium and ^{241}Am Concentrations in Marine Invertebrates from Regions of the Pacific Ocean 22
Plutonium and ^{241}Am Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and Mediterranean Sea 24
Cesium-137 Concentrations in Marine Fish from Regions of the Pacific Ocean 32
Cesium-137 Concentrations in Marine Fish from Regions of the Atlantic and Indian Oceans and Mediterranean Sea. 40
Cesium-137 Concentrations in Marine Invertebrates from Regions of the Pacific Ocean 50
Cesium-137 Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and Mediterranean Sea. 53
Strontium-90 Concentration in Marine Fish from Regions of the Pacific Ocean 58
Strontium-90 Concentrations in Marine Fish from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea 62
Strontium-90 Concentrations in Marine Invertebrates from Regions of the Pacific Ocean 67
Strontium-90 Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea 69
Cobalt-60 Concentrations in Marine Fish from Regions of the Pacific Ocean 73
Cobalt-60 in Marine Fish from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea 77
Cobalt-60 Concentrations in Marine Invertebrates from Regions of the Pacific Ocean. 78
Cobalt-60 Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea 81
Concentrations of the Natural Radionuclides (Polonium to Uranium) in Marine Fish from Regions of the World Oceans 83
Concentrations of the Natural Radionuclides (Polonium to Uranium) in Invertebrates 89

TABLES

1. Concentration Factors for Plutonium and ^{241}Am in Fish. 20
2. Concentration Factors for Plutonium and ^{241}Am in Invertebrates. 30
3. Concentration Factors for ^{137}Cs in Fish 48
4. Concentration Factors for ^{137}Cs in Invertebrates 57
5. Concentration Factors for ^{90}Sr in Fish 66
6. Concentration Factors for ^{90}Sr in Invertebrates 72
7. Concentration Factors for ^{60}Co in Fish 78
8. Concentration Factors for ^{60}Co in Invertebrates 85
9. Concentration Factors for the Natural Radionuclides (Polonium to Uranium) in Fish. 88
10. Concentration Factors for the Natural Radionuclides (Polonium to Uranium) in Invertebrates. 93

FOREWORD

In response to the mandate of Public Law 92-532, the Marine Protection, Research and Sanctuaries Act of 1972, as amended, the Environmental Protection Agency (EPA) has developed a program to promulgate regulations and criteria to control the ocean disposal of radioactive wastes. An important technical consideration in any environmental assessment of this option is the potential for biomagnification of radioactivity in marine food chains which could lead to man. An understanding of the range of concentrations and concentrating mechanisms of key radionuclides found in marine organisms is fundamental.

This report represents a comprehensive compilation of information pertaining to field-derived radionuclide concentrations and concentration factors in marine biota for isotopes of plutonium, americium, cesium, strontium, cobalt and the natural radionuclides polonium, radium, thorium and uranium. The data, presented in annotated bibliographic format, are organized by different regions of the world oceans, facilitating comparison of radionuclide values from regions subject only to atmospheric fallout with values from regions influenced by a variety of sources. Tables of concentration factors by radionuclide are presented for marine vertebrates and invertebrates according to trophic structure and by tissue analyzed, where possible.

It is anticipated that the data in this report will provide a comparison for the concentrations and concentration factors of radioactivity obtained for biota which continue to be collected from various ocean areas. The data may also be included in predictive models to estimate concentrations of specific nuclides which may occur in fish or invertebrates from any future ocean disposal activities, and to predict the resultant dose to man from ingestion of these seafoods. A companion document on laboratory-derived radionuclide concentrations and concentration factors will be published in 1985.

The agency invites all readers of this report to send any comments or suggestions to Mr. David E. Janes, Director, Analysis and Support Division, Office of Radiation Programs (ANR-461), Environmental Protection Agency, Washington, D.C. 20460.

Sheldon Meyers

Sheldon Meyers, Acting Director
Office of Radiation Programs

Concentrations and Concentration Factors of Several Anthropogenic and Natural Radionuclides in Marine Vertebrates and Invertebrates

ABSTRACT

The literature is reviewed and summarized with regard to concentrations of several anthropogenic and natural radionuclides in biological organisms from marine environments. Reported concentration factors for these radionuclides in organisms are tabulated for marine fish and invertebrates from water masses affected by different source terms.

INTRODUCTION

This document is a review of a selected number of papers and reports published prior to 1984 reporting on concentrations and concentration factors (CFs*) of several anthropogenic and natural radionuclides in marine invertebrates and fish from field studies conducted at various global locations. The literature on concentrations in marine algae is not included in this review. Radionuclides reviewed and included in this report are, in the sequences presented in compilations, ^{238}, $^{239+240}$Pu, ^{241}Am, ^{137}Cs, ^{90}Sr, ^{60}Co, and longer-lived radionuclides of the uranium and thorium decay chains. The listing of results for these particular radionuclides was requested by the Office of Radiation Programs of the United States Environmental Protection Agency to aid in their environmental assessments. This author anticipates that this data bank will be updated in the future and include listings of other appropriate radionuclides of possible concern to radioactive waste disposal practices in the marine environment.

There is a need to understand the impact on both man and the biosphere of radionuclides introduced to the marine environment. The principal purpose then of this review is to provide an annotated bibliography of selected papers and reports and a

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* CF (Concentration factor, Bioaccumulation factor, Concentration Ratio), a value relating the concentration in the organism or part of the organism (usually expressed per unit wet weight) to that in sea water:

$$CF = \frac{\text{pCi/g organism}}{\text{pCi/g seawater}}$$

current listing of field-determined concentration factors for different tissues of organisms and to show, in some cases, the variability in the reported values and in others, the paucity of results for some of the radionuclides reviewed. These CFs could be used in conjunction with models requiring such data (concentration factor approach) to estimate probable concentrations of different radionuclides in fish and invertebrates in a water mass near or distant from a source of input to the ocean. If man eventually consumes any of the edible marine organisms, the values presented will aid in increasing the accuracy in estimated dosage to man from the ingestion of marine foods. However, it was beyond the scope of this review to evaluate the accuracy or reliability of the reported information that could possibly affect the variations noted in the values of concentration factors. In most instances it was not possible to distinguish if a reported value was computed relative to the concentration in filtered or unfiltered water. Because there are also a number of judgements (not considered in this review) which have to be made such as to what amounts of the different parts of marine organisms are likely to be consumed by man, no mean or generic values are recommended. The reader therefore should exercise care in selecting values from the tables of results provided for a particular application. A few concentration factors based on stable element determinations are referenced but are not listed in the companion tables. A "user guide", discussing the factors and complications affecting the concentration factor values summarized in this report, is being considered for publication in the near future.

ORGANIZATION OF REFERENCES

References to the concentrations measured in organisms collected from regions of the Pacific affected by different source terms are distinguished from studies in the Atlantic-Indian Oceans and the Mediterrean Sea. An effort was made to relate specific studies to source terms for the different radionuclides. The source terms identified in this review include:

1. Worldwide fallout from atmospheric nuclear explosions
2. Reactor releases to coastal environments
3. Leakage from solid waste disposal sites in the deep ocean
4. Close-in failout from the Pacific Proving Grounds
5. Pipeline discharges from nuclear reprocessing facilities
6. Close-in fallout from non-nuclear events

References containing field-determined concentration factors are listed separately. Complete literature references are only provided once in the section in which they first appear. The sections are arranged in the radionuclide sequence previously described. The reader requiring a ^{137}Cs reference involving a study of both $^{239+240}Pu$ and ^{137}Cs will be referred back to the respective document in the plutonium section. When replication of the results was noted, only one entry was made in the tables of concentration factors and all references to the respective result are noted in the tables.

This author regrets if any reference related to environmental concentrations of the selected radionuclides is not included in this bibliography. It is hoped that any reader or user of this document will inform the author and/or the Environmental Protection Agency of any relevant old or new information which will subsequently be incorporated in a revision of this compilation at some future date.

ACKNOWLEDGEMENTS

Mr. R. J. Eagle, Lawrence Livermore National Laboratory, is gratefully thanked for preparing the animal classifications and trophic level assignments which appear in the tables of this report. This work was performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48 with support by the Office of Radiation Programs, United States Environmental Protection Agency (DOE-EPA Interagency Agreement A089F00070).

ANNOTATED BIBLIOGRAPHY

Plutonium and ^{241}Am Concentrations in Marine Fish from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for $^{239+240}Pu$ and ^{241}Am.

Pu-1. Pillai, K.C., Smith, R.C., and Folsom, T.R., "Plutonium in the Marine Environment," Nature 203, 568 (1964). One of the first attempts to determine fallout plutonium in seawater and marine organisms. The authors report a concentration of 0.0014 ± 0.0018 pCi/kg wet wt. in the edible portion and bones of a single bonito caught in 1964 near the coast of Southern California. The measured concentration was less than the detection limits, yet based on the concentration measured in the water, an upper limit value of three was computed for the concentration factor (CF) of plutonium in the tissue analyzed. No ^{238}Pu or ^{241}Am concentrations were reported.

Pu-2. Noshkin, V.E., Wong, K.M., Jokela, T.A., Eagle, R.J., and Brunk, J.L., Radionuclides in the Marine Environment near the Farallon Islands, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52381 (1978) 17 pp. Concentrations of $^{239+240}Pu$ are reported in pooled tissue of rockfish collected near the Farallon Islands waste disposal site in 1977. The concentration of $^{239}{}_{+}{}^{240}Pu$ in the flesh was 0.008 pCi/kg wet. No ^{238}Pu or ^{241}Am concentrations are reported. A concentration factor for plutonium may be computed by using the average water concentration of 0.00067 pCi/l determined between the surface layer and 100 meters.

Pu-3. Kurabayashi, M., Fukuda, S., and Kurokawa, Y., "Concentration Factors of Marine Organisms Used for the Environmental Dose Assessment," Marine Radioecology (Proc. 3rd NEA Sem. Tokyo 1979), OECD, Paris (1980) 335. Average concentration and the range of $^{239+240}Pu$ are reported in whole Shirasu (young anchovy) and the flesh of adult fish (flounder and flatfish) obtained between 1971 and 1975 along the coast offshore from the Tokai fuel reprocessing plant, Tokai-mura, Japan. For whole Shirasu, concentrations

ranged from 0.015 to 0.085 pCi/kg wet wt. and averaged 0.036 pCi/kg. Concentrations in the flesh of adult fish ranged between 0.002 and 0.371 pCi/kg wet, averaging 0.099 pCi/kg. Concentration factors for $^{239+240}$Pu are computed. There are no reported ^{238}Pu or ^{241}Am concentrations.

2. Some additional references to fallout levels in Pacific fish; no reported CF.

Pu-4. Hodge, V.F., Folsom, T.R., and Young, D.R., "Retention of Fallout Constituents in Upper Layers of the Pacific Ocean as Estimated from Studies of a Tuna Population," Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle 1972), IAEA, Vienna (1973), 263. $^{239+240}$Pu levels are reported in pooled samples of liver from albacore collected off San Diego, CA between 1964 and 1971. Liver concentrations ranged from 0.062 to 0.223 pCi/kg wet wt. during this period. An apparent half-time of residence of 3.5 years is estimated for $^{239+240}$Pu in the upper layers of the North Pacific. No ^{238}Pu or ^{241}Am concentrations are reported. No CF are computed.

Pu-5. Folsom, T.R., "A Summary of Records of Concentrations of 8 Different Fallout Nuclides Observed in Tissues of Albacore Caught West of California 1964-1977," Environmental Quarterly Report, United States Department of Energy Environmental Measurements Laboratory, New York, NY, EML-356 (1979) I-136. Levels of $^{239+240}$Pu in pooled samples of liver from albacore and other tuna from regions of the Pacific between 30-50°N, 120-140°W, ranged from 0.09 to 0.47 dpm/kg wet wt. The samples were obtained between 1968 and 1977. No ^{238}Pu or ^{241}Am measurements are reported. No CF were computed.

Pu-6. Schell, W.R., and Sugai, S., "Radionuclides at the U.S. Radioactive Waste Disposal Site Near the Farallon Islands," Health Phys. 39, 475 (1980). A large variety of fish including sablefish, short-spine thornyhead, rat-tail, deepsea sole, Pacific flatnose, lanternfish, eared blacksmelt, midshipman, Pacific sanddab, rock sole, Pacific hake, twoline eelpout and Dover sole were obtained from the vicinity of the Farallon Islands during August, September, and October 1977 for radionuclide analysis. Some fish were dissected into various tissues and organs of interest for analysis and others were pooled and analyzed whole for $^{239+240}$Pu, ^{238}Pu and other radionuclides. No ^{241}Am measurements were

reported. Of the 87 reported values of $^{239+240}Pu$ concentrations, detection limits were exceeded in only 5 samples of vertebrate tissues and ^{238}Pu was above detection limits in 11 samples. All concentrations are reported on a dry weight basis and the associated error is expressed as ± 2 standard deviations of the counting error. No CF values are reported. $^{239+240}Pu$ concentrations in edible muscle tissue were less than 6 pCi/kg dry (0.8 pCi/kg wet) for all species analyzed.

B. Central Pacific Atolls and Other Locations Possibly Affected (Source Term--Local Fallout from the Pacific Nuclear Test Sites)

1. References containing field-derived concentration factors for $^{239+240}Pu$ and ^{241}Am.

Pu-7. Nevissi, A., and Schell, W.R., "^{210}Po and ^{239}Pu, ^{240}Pu in biological and water samples from the Bikini and Enewetak Atolls," Nature **255**, 321 (1975). $^{239+240}Pu$ concentrations are reported in the tissues of several species of fish from Bikini and Enewetak Atolls collected during October 1972. CF are computed and range from less than 20 to 1.5×10^3 for muscle tissue of different species.

Pu-8. Noshkin, V.E., Wong, K.M., and Eagle, R.J., "Plutonium Concentrations in Fish and Seawater from Kwajalein Atoll," Health Phys. **37**, 549 (1979). This is a follow-up study to assess the concentrations of $^{239+240}Pu$ in fish from Kwajalein Atoll (see Ref. Pu-15). Concentrations of $^{239+240}Pu$ in tissues and organs of mullet and snapper from the atolls are provided and CFs are computed from the environmental data. In the muscle of snapper the concentration was 0.003 ± 0.001 pCi/kg wet. The authors show the concentrations of plutonium are significantly less than those measured during the 1972 survey and the earlier results are inconsistent with other environmental data from the lagoon.

Pu-9. Noshkin, V.E., Eagle, R.J., Wong, K.M., and Jokela, T.A., "Transuranic Concentrations in Reef and Pelagic Fish from the Marshall Islands," Impacts of Radionuclide Releases Into the Marine Environment (Proc. Symp. Vienna 1980), IAEA, Vienna (1981) 293. This report summarizes the $^{239+240}Pu$ results presented in Ref. Pu-18 and also provides recent measurements of

concentrations in fish from Bikini and Enewetak Atolls. CF are computed for $^{239+240}Pu$ in the muscle of different fish from all locations sampled. ^{241}Am concentrations are mentioned but not discussed in great detail. Relationships among concentrations in different organs and tissues of fish are discussed.

2. Additional references to $^{239+240}Pu$ and ^{241}Am concentrations in fish from Pacific Atolls; no concentration factors provided.

Pu-10. Thomas, C.W., Reid, D.L., and Lust, L.F., Radiochemical Analysis of Marine Biological Samples Following the Redwing Shot Series--1956, U.S. AEC Document, HW-58674, UC-41 Health and Safety, TID-4500, 15th Ed., (1958) 85. A variety of biological samples were collected for radionuclide analysis between June 1956 and June 1957 from the islands of Guam, Saipan, Ulithi, Yap and Palau in the Western Pacific Ocean. Fish were dissected to provide muscle, liver, head and backbone samples for radionuclide analysis. $^{239+240}Pu$ was above detection limits in 16 of the 80 samples of vertebrate tissue samples analyzed. In fish muscle, concentrations ranged from 0.02 to 0.26 10^{-6} μCi/g wet wt. No ^{238}Pu or ^{241}Am measurements are reported. Concentration factors were not determined.

Pu-11. Welander, A.D., "Distribution of Radionuclides in the Environment of Enewetak and Bikini Atolls, August 1964," Symposium on Radioecology, D.J. Nelson and F.C. Evans, Eds., United States Atomic Energy Commission, Washington, D.C., CONF-670503 (1969) 346. $^{239+240}Pu$ concentrations in sections of surgeonfish, damselfish and snapper caught at Bikini Island, Bikini Atoll in 1964 ranged from 1.0 to 7.5 pCi/g dry wt. No ^{241}Am or ^{238}Pu results are provided. No concentration factors are computed.

Pu-12. United States Atomic Energy Commission, Enewetak Radiological Survey, United States Atomic Energy Commission Nevada Operations Office, Las Vegas, NV, NVO-140 (1973), Vols. I - III. This is a summary and partial discussion of the results from a radiological survey of Enewetak Atoll conducted in 1972-1973. Concentrations of $^{239+240}Pu$ are reported in different tissues and organs from a variety of reef and lagoon pelagic species collected from different atoll locations. In addition, fish were also obtained for analysis of plutonium and other radionuclides from Kwajalein Atoll, considered

to be a control site not contaminated with radionuclides from local fallout. All results are expressed in terms of dry weight of tissues analyzed but wet/dry weight ratios are provided for conversion purposes. At Kwajalein, eviscerated whole fish concentrations ranged from 0.004 to 0.96 pCi/g dry. Any measurable concentration of ^{241}Am by gamma spectrometry in the fish samples is reported. CF are not provided but can be determined using concentrations measured in the lagoon water from the vicinity where fish were collected.

Pu-13. Wilson, D.W., Ng, Y.C., and Robison, W.L., "Evaluation of Plutonium at Enewetak Atoll," Health Phys. **29**, 599 (1975). This report is specifically a summary of the plutonium results from the Enewetak Survey Report (Ref. Pu-12). The authors conclude that the concentration of $^{239+240}Pu$ in fish was not strongly dependent on the species or on the location of the catch. The average concentration for pelagic fishes plus reef fish was 0.248 pCi/g (dry wg) and ranged between 0.005 to 23 pCi/g (dry wg).

Pu-14. Schell, W.R., and Watters, R.L., "Plutonium in Aqueous Systems," Health Phys. **29**, 589 (1975). This report provides some data on concentrations of $^{239+240}Pu$ and ^{241}Am (pCi/g dry) in fish collected during the 1972 survey of Enewetak and Kwajalein Atolls. Concentrations of $^{239+240}Pu$ in muscle and eviscerated whole fish ranged from less than 0.003 to 0.04 pCi/g dry. ^{241}Am was below limits of detection. The authors conclude that the plutonium and americium concentrations measured in the convict surgeonfish, for example, are not significantly higher than those values measured at the control station, Kwajalein Atoll. No CF values are reported.

Pu-15. Noshkin, V.E., Eagle, R.J., and Wong, K.M., "Plutonium Levels in Kwajalein Lagoon," Nature **262**, 745 (1976). Concentrations of $^{239+240}Pu$ in fish collected during the 1972-1973 survey of Enewetak and Kwajalein Atolls are summarized. Average concentrations of plutonium in fish muscle, bone and viscera samples from Enewetak were 0.013, 0.038 and 0.45 pCi/g dry, respectively. The results show that the average level of $^{239+240}Pu$ in fish bone, muscle and gut from Enewetak Atoll are similar to, or even lower than, those of the fish indigenous to the control station, Kwajalein Lagoon. Several possibilities are suggested to account for these anomalous results. CF for plutonium are not provided. No ^{238}Pu or ^{241}Am results are reported.

Pu-16. Nelson, V.A., Radiological Survey of Plants, Animals and Soil at Christmas Island and Seven Atolls in the Marshall Islands, Progress Report for 1974-1975, United States Atomic Energy Commission Nevada Operations Office, Las Vegas, NV, NVO-269-32 (January 1977), 69 pp. Concentrations of $^{239+240}Pu$ in parts of fish collected at Bikini Atoll in December 1974 and April 1975 are given. All results are expressed as pCi/g dry wt. Concentrations in eviscerated whole fish ranged from 0.002 to 0.019 and in viscera samples the range of $^{239+240}Pu$ concentration was 0.05 to 5.5. No ^{241}Am or ^{238}Pu concentrations are given. No CF are computed.

Pu-17. Nelson, V.A., Radiological Survey of Plants, Animals and Soil in Micronesia, Unites States Atomic Energy Commission Nevada Operations Office, Las Vegas, NV, NVO-269-35 (January 1979), 31 pp. Measurements of $^{239+240}Pu$ were attempted in fish samples collected from Majuro Atoll, Ponape, and Palau. These sites did not receive appreciable (or any) fallout from the nuclear tests at Bikini and Enewetak Atolls. All samples analyzed from these locations contained less than 0.007 pCi/g dry wt. of $^{239+240}Pu$. All reported values were less than detection limits. No ^{238}Pu or ^{241}Am values are given. No CF are tabulated.

Pu-18. Noshkin, V.E., Eagle, R.J. Wong, K.M., Jokela, T.A., Brunk, J.L., and Marsh, K.V., Concentrations of Radionuclides in Reef and Lagoon Pelagic Fish from the Marshall Islands, Lawrence Livermore National Laboratory, Livermore, CA, UCID-19028 (1981) 64 pp. $^{239+240}Pu$, ^{238}Pu, and ^{241}Am concentrations in a variety of dissected fish parts from different species collected during a 1978 survey of Rongelap, Utirik, Taka, Bikar, Rongerik, Ailinginae, Likiep, Jemo, Ailuk, Mejit, Wotho and Ujelang Atolls are provided. The atolls surveyed received different amounts (ranging to zero) of local fallout from the tests conducted at Bikini and Enewetak Atolls. All concentration data are expressed as pCi/kg wet wt. and dry/wet weight ratios are provided for conversion purposes. Average levels of $^{239+240}Pu$ in the flesh of fish from the different atolls ranged from less than 0.003 to 0.30 pCi/kg wet. A table of comparative concentrations from other global locations is also shown and includes some recent measurements in U.S. and foreign market fish samples.

Pu-19. Noshkin, V.E., Wong, K.M., Eagle, R.J., and Anglin, D.L., "Concentrations of ^{113m}Cd in the Marine Environment," Nature 287, 221 (1980). This report specifically discusses the presence of ^{113m}Cd in marine organisms from Pacific Atolls but includes some concentrations of $^{239+240}$Pu (0.003 to 1.8 pCi/g) and ^{241}Am (0.012 to 0.36 pCi/g) in fish liver samples for comparative purposes. All results are expressed as pCi/g dry weight. No CFs are computed.

Pu-20. Noshkin, V.E., Wong, K.M., Eagle, R.J., and Anglin, D.L., "Detection of Cadmium Radioactivity in the Marine Environment," Impacts of Radionuclide Releases into the Marine Environment (Proc. Symp. Vienna, 1980) IAEA, Vienna (1981) 685. As in Ref. Pu-19, the discussion centers on ^{113m}Cd concentrations but includes some measurements of $^{239+240}$Pu in selected marine samples from Pacific Atolls and in mullet from North Carolina. Results are expressed in pCi/g dry weight but dry/wet weight ratios are provided for conversion purposes. No ^{238}Pu or ^{241}Am data are provided and CF are not computed.

Plutonium and ^{241}Am Concentrations in Marine Fish from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for $^{239+240}$Pu and ^{241}Am.

Pu-21. Wong, K.M., Burke, J.C., and Bowen, V.T., "Plutonium Concentrations in Organisms of the Atlantic Ocean," in Proceedings, Fifth Annual Health Physics Society Midyear Topical Symposium: Health Physics Aspects of Nuclear Facility Siting, Ramada Inn, Idaho Falls, Idaho, Nov. 3-6, 1970. Vol. 2 (1971), 529. Concentrations and CFs for $^{239+240}$Pu were determined in several fish collected from regions of Cape Cod, MA, and the open North Atlantic Ocean. The fishes analyzed included blue shark, blue fin tuna, bluefish, striped bass, tautog and blackback flounder. Concentrations in some of the muscle, bone, liver gut and gill samples were determined. In muscle tissue the concentrations

of plutonium ranged from 0.2 to 0.7 dpm/100 kg wet wt. (0.0009 to 0.003 pCi/kg). Concentration factors for $^{239+240}$Pu in fish muscle range from 1 to 5 with an average value of 3 ± 2. No ^{241}Am or ^{238}Pu results were published.

Pu-22. Noshkin, V.E., "Ecological Aspects of Plutonium Dissemination in Aquatic Environments," Health Phys. 22, 537 (1972). This is a review of the literature available through 1971 on the concentrations of plutonium in the marine environment. Concentrations factors obtained from the literature are reviewed. Included are the results from Refs. Pu-1, Pu-10, Pu-11, Pu-21, and Pu-33 and some previously unpublished data. The CF for $^{239+240}$Pu in fish muscle ranges from 1 to 13 with a mean of 5 ± 4.

2. Some additional references to concentrations accumulated by Atlantic fish; no reported CF.

Pu-23. Bowen, V.T., Livingston, H.D., and Burke, J.C., "Distributions of Transuranium Nuclides in Sediment and Biota of the North Atlantic Ocean," Transuranium Nuclides in the Environment (Proc. Symp. San Francisco 1975) IAEA, Vienna (1976), 107. Concentrations of $^{239+240}$Pu in various parts of bottom feeding and water column feeding fish as well as in large predators collected from regions of the North Atlantic Ocean are tabulated. Fish muscle concentrations range from less than 0.003 to 0.18 dpm/kg wet wt. No CFs were determined. No ^{238}Pu or ^{241}Am data for marine vertebrates were provided.

Pu-24. Miettinen, J.K., "Plutonium Foodchains," Environmental Toxicity of Aquatic Radionuclides: Models and Mechanisms, Miller, M.W. and Stannard, J.N., Eds., Ann Arbor Science, Ann Arbor, Mich., (1976) 29. Miettinen, J.K., Jaakkola, T., and Järvinen, M., "Plutonium Isotopes in Aquatic Foodchains in the Baltic Sea," Impacts of Nuclear releases in the Aquatic Environment (Proc. Symp. Otaniemi 1975), IAEA, Vienna (1975) 147. Both references include the results of concentrations for $^{239+240}$Pu determined in the entire sample of ruff (Acerina cernus) and flounder (Platichthys flesus) and in skin and liver samples of cod (Gadus morrhua) collected in the Gulf of Finland during 1974. Concentrations are expressed as pCi/kg wet and dry and ranged from 0.04 to 0.09 pCi/kg wet wt. in the whole fish. No CF are computed and no results for ^{238}Pu or ^{241}Am are given.

Pu-25. Bowen, V.T., Transuranic Elements in Marine Environments, United States Department of Energy Health and Safety Laboratory, New York, NY, HASL 291 (1975), I-58. This is a summary paper of transuranic elements in marine environments. The author states that fish show a low CF: average about 5 in muscle tissue, with only one observation above 10; bone, liver or intestine CF may range up to 50 or 75 and differences among fish species, even those occupying very similar places in the food web, have proved large and unpredictable.

Pu-26. Livingston, H.D., and Bowen, V.T., Contrasts between the Marine and Freshwater Biological Interactions of Plutonium and Americium, United States Atomic Energy Commission Health and Safety Laboratory, New York, NY, HASL 315 (1977), I-157. This is a different discussion of the fish concentration data presented in Ref. Pu-23. The authors indicate that the levels of fallout plutonium measured in marine and fresh water animals are the same; that food, or particulate matter ingested with the food, is the major source of plutonium, that much of this plutonium is available for absorption by the gut, but that deposition and retention in tissues (even in bone) are relatively short term. No CF are provided.

Pu-27. Higgo, J.J.W., and Cherry, R.D., Plutonium and Other Alpha Radioactive Isotopes in Marine Organisms in the Southern Hemisphere, United States Department of Energy Environmental Measurements Laboratory, New York, NY, EML-342 (1978) I-23. $^{239+240}$Pu concentrations are determined in tissues of hake and tuna collected from South African waters around Cape Town in 1972 and 1973. Levels in flesh were less than 0.01 pCi/kg wet. Highest concentrations were detected in the gut of the hake (0.30 ± 0.05 pCi/kg wet). These are the only measurements of fallout plutonium in fish from the Southern Hemisphere. No CF were assessed; no concentrations of ^{238}Pu or ^{241}Am in marine vertebrates were reported.

Pu-28. Hayes, D.W., and Horton, J.H., "Plutonium and Americium Behavior in the Savannah River Marine Environment," in Transuranic Elements in the Environment, W.C. Hanson, Ed.,United States Department of Energy, Washington, D.C., TIC-22800 (1980), 602. Concentrations of $^{239+240}$Pu are reported for several fish collected in or near the Savannah River estuary. Concentrations in mullet were 0.005 pCi/kg wet; in speckled trout, 0.004 pCi/kg

wet; and in shad, 0.001 pCi/kg wet. The parts of the fish analyzed are not indicated or is the year of collection stated. No ^{238}Pu or ^{241}Am concentrations are reported and CFs are not computed.

Pu-29. Anon., Other Radionuclide Sampling, Plutonium, United States Atomic Energy Commission Health and Safety Laboratory, New York, NY, HASL-77 (1960), I-151. Levels of plutonium in commercially available swordfish analyzed in 1959 ranged from 0.3 to 1.0 pCi/kg. It is not known if these represent dry or wet weight concentrations. The information was extracted from an AEC press release of Oct. 9, 1959. No CFs are reported.

Pu-30. Bennett, B.G., "Transuranic Element Pathways to Man", Transuranium Nuclides in the Environment, (Proc. Symp. San Francisco 1975) IAEA, Vienna (1976), 367. Fallout levels of $^{239+240}Pu$ are shown for New York dietary items analyzed in 1972. Shellfish contained 0.011 pCi/kg wet and the concentration of Pu in fresh fish was 0.0016 pCi/kg.

Pu-31. Bennett, B.G., Fallout $^{239+240}Pu$ in Diet, 1974 Results, United States Atomic Energy Commission Health and Safety Laboratory, New York, NY, HASL-306 (1976), I-115. Fallout levels of $^{239+240}Pu$ are shown for New York dietary items analyzed in 1974. Shellfish contained 0.04 pCi/kg wet and the concentration of Pu in fresh fish was 0.0017 pCi/kg.

Pu-32. Noshkin, V.E., "Fallout Concentration in Sediments and Some Biota from Regions of the North-East Atlantic," Interim Oceanographic Description of the North-East Atlantic Site for the Disposal of Low-Level Radioactive Waste, Nuclear Energy Agency, OECD, Paris (1983), 119-124. Concentrations of $^{239+240}Pu$ and ^{241}Am are reported for parts of fish collected in traps from 2100 m in the Bay of Biscay during 1981. $^{239+240}Pu$ concentrations in muscle and eviscerated fish were less than 0.1 pCi/kg wet. ^{241}Am levels generally exceeded those of $^{239+240}Pu$ in the parts analyzed.

B. Environments Contaminated with Local Inputs (Source Term--Close-In Fallout, Non-Nuclear, Thule, Greenland).

1. References containing field derived concentration factors. No CFs provided.

Pu-33. Aarkrog, A., "Radioecological Investigations of Plutonium in an Arctic Marine Environment," Health Phys. 20, 31 (1971). Fish and other samples of the marine food chain at Thule, Greenland, were collected during the summer of 1968 for plutonium analysis. The plutonium in this environment resulted from the nuclear weapon incident in January of 1968. $^{239+240}$Pu levels in fish collected at different distances from the crash site are compiled. The median concentration for all fish was 36 pCi/kg fresh wt. and ranged from 0.26 to 470 pCi/kg. Some concentrations in the stomach of walrus and seal (marine mammals) are also tabulated. CF are not computed. The concentration of ^{238}Pu (7.0 pCi/kg fresh wt.) was determined in one sample of Greenland halibut. No ^{241}Am results are provided.

Pu-34. Aarkrog, A., "Environmental Behaviour of Plutonium Accidentally Released at Thule, Greenland," Health Phys. 32, 271 (1977). This is a follow-up to the previous study of plutonium in this environment (see Ref. Pu-33). Additional concentrations of $^{239+240}$Pu are reported in parts of fish collected from the region during 1970 and 1974. The geometric mean levels in fish collected in 1970 and 1974 were 4 and 1 pCi/kg fresh wt., respectively; an order of magnitude less than values determined in 1968.

Pu-35. Aarkrog, A., "Plutonium Levels in the Marine Environment at Thule, Greenland," Marine Radioecology (Proc. 3rd NEA Sem., Tokyo 1979) OECD, Paris (1980) 245. A summary of the $^{239+240}$Pu levels in fish and in other environmental samples from the vicinity of Thule is presented and includes the results discussed in Refs. Pu-33 and Pu-34.

Pu-36. Aarkrog, A., Dahlgaard, H., Holm, E., Hansen, H., Lippert, J., and Nilsson, K., Environmental Radioactivity in Greenland in 1981, Riso National Laboratory Report, RISO-R-471 (1982). Uncommented tables are provided showing $^{239+240}$Pu and ^{241}Am concentrations in fish and invertebrates collected at Thule in August 1979. During this period the concentration of $^{239+240}$Pu in the flesh was 0.043 pCi/kg wet. The concentration of ^{241}Am was 13% of the plutonium concentration. No CF factors are provided.

C. Coastal Regions (Source Term--Reprocessing Facilities Discharges)

1. References containing field-derived concentration factors for $^{239+240}Pu$ and ^{241}Am in fish from both the immediate vicinity and at distances from release points.

Pu-37. Hetherington, J.A., Jefferies, D.F., and Lovett, M.B., "Some Investigations into the Behaviour of Plutonium in the Marine Environment," Impacts of Nuclear Releases into the Aquatic Environment, (Proc. Symp. Otaniemi 1975), IAEA, Vienna (1975), 193. The authors provide two tables related to concentrations of $^{239+240}Pu$ in fish. The first compares the concentrations in fish collected within 5 km of the Windscale outfall to those in fish at commercial landings from the northeastern Irish Sea between 1970 and 1974. Results are expressed as a percent of a derived working limit. The mean concentration of $^{239+240}Pu$ in the flesh of fish caught throughout an area of radius 100 km from Windscale is some 30 times less than the concentration in the fish taken from the immediate area of the discharge point. The second table provides CF of $^{239+240}Pu$ in the flesh of plaice (Pleuronectes platessa), dab (Limanda limanda) and salmon (Salmo salar). For the two demersal fish, dab and plaice, caught within 5 km of the outfall, the CF is 30 while the value for salmon is reported as 1.0. No ^{238}Pu or ^{241}Am results are reported.

Pu-38. Pentreath, R.J., and Lovett, M.B., "Occurrence of Plutonium and Americium in plaice from the North-Eastern Irish Sea," Nature 262, 814 (1976). During 1975 four catches of plaice were made approximately 5 km south of the Windscale pipeline. $^{239+240}Pu$, ^{238}Pu, and ^{241}Am levels were measured in separated kidney, liver, gut, gut contents, gill, skin, bone, and muscle samples. Fish muscle concentrations of $^{239+240}Pu$ and ^{241}Am ranged from 0.16 to 0.47 and from 0.3 to 2.3 fCi/g wet wt., respectively. CF over seawater (filtrate) for the samples of muscle collected in August 1975 are reported to be on the order of less than 1 for $^{239+240}Pu$ and approximately 5 for ^{241}Am.

Pu-39. Pentreath, R.J., and Lovett, M.E., "Transuranic Nuclides in Plaice (Pleuronectes platessa) from the North-Eastern Irish Sea," Marine Biol. 48, 19 (1978). The concentrations of ^{238}Pu, $^{239+240}Pu$, and ^{241}Am are determined in the organs of plaice caught in the vicinity of the nuclear fuel reprocessing plant at Windscale, Cumbria, England. Fish were taken for analysis every 3 months

for a period of 2 years between 1975 and 1977. During this period the highest concentrations of plutonium (19-88 fCi/g wet) and americium (47-440 fCi/g wet) nuclides were found in the kidney. In all the organs analyzed, the concentration of ^{241}Am was greater than that of plutonium. CF for plutonium and americium in the different organs are computed.

Pu-40. Fraizier, A., and Guary, J.C., "Recherche D'Indicateurs Biologiques Appropries Au Controle De La Contamination Du Littoral Par Le Plutonium," Transuranium Nuclides in the Environment (Proc. Symp. San Francisco 1975) IAEA, Vienna (1976), 679. The accumulation of plutonium by a number of marine species, including fish, from a coastal site near the La Hague Reprocessing Facility is discussed. CF for plutonium in some fish tissues are presented.

Pu-41. Guary, J.C., Masson, M., and Fraizier, A., "Etude Preliminaire, in situ, de la Distribution du Plutonium Dans Differents Tissus et Organes det Cancer Pagurus (Crustacea: Decapoda) et de Pleuronectes Platessa (Pisces: Pleuronectidae)," Marine Biol. **36**, 13 (1976). Plutonium concentrations are determined in the tissues and organs of plaice collected inshore near the La Hague fuel reprocessing plant and ranged from 0.11 pCi/kg in muscle to 64 pCi/kg in the GI tract. CF are reported for plutonium in the different tissues analyzed.

2. Additional references to $^{239+240}Pu$ and ^{241}Am concentrations in fish from the vicinities of waste reprocessing facilities.

Pu-42. Pentreath, R.J., Lovett, M.B., Harvey, B.R., and Ibbett, R.D., "Alpha-Emitting Nuclides in Commercial Fish Species Caught in the Vicinity of Windscale, United Kingdom, and Their Radiological Significance to Man," Biological Implications of Radionuclides Released from Nuclear Industries, (Proc. Symp. Vienna 1979) IAEA, Vienna (1979), 227. The concentrations of plutonium and ^{241}Am are reported in the tissues of several commercial fish from the vicinity of the Windscale plant discharges and in commercial fish fillets from the Irish Sea. Fish caught at increasing distances from Windscale contain significantly lower concentrations of $^{239+240}Pu$ and ^{241}Am than the levels detected in fish collected near the discharge point. The muscle of cod caught within 5 km of the pipeline contained from 0.84 to 2.0 fCi/g wet of $^{239+240}Pu$, while in cod at distances of 124 to 287 km from Windscale the range in muscle concentration was from less than 0.001 to 0.0059 fCi/g wet.

Pu-43. Pentreath, R.J., "Radionuclides in Marine Fish," Oceanogr. Mar. Biol. Ann. Rev. 15, 365 (1977). The author reviews available literature through 1976 on the accumulation by fish of many radionuclides, including $^{239+240}Pu$ and ^{241}Am. Tables of data provided include the results published in Ref. Pu-38.

Pu-44. Hetherington, J.A., Jefferies, D.F., Mitchell, N.T., Pentreath, R.J., and Woodhead, D.S., "Environmental and Public Health Consequences of the Controlled Disposal of Transuranic Elements to the Marine Environment," Transuranium Nuclides in the Environment (Proc. Symp. San Francisco 1975) IAEA, Vienna (1976), 139. Concentrations of $^{239+240}Pu$ and ^{241}Am are reported in the flesh of plaice, dab and herring collected during 1974 from the Windscale vicinity and from the north eastern Irish Sea (commercial landings at Whitehaven). Levels of plutonium in muscle of fish from Windscale were less than 0.01 pCi/g fresh wt. while at Whitehaven, muscle levels ranged from 0.0002 to 0.0007 pCi/g wet. Concentrations of $^{239+240}Pu$, ^{238}Pu, and ^{241}Am are reported in several tissues and organs of plaice collected during 1975 at Windscale. ^{241}Am levels exceed $^{239+240}Pu$ concentrations in all fish parts analyzed.

Pu-45. Hunt, G.J., "Radioactivity in Surface and Coastal Waters of the British Isles, 1977, 1978, 1979, 1980," Ministry of Agriculture, Fisheries and Food, Directorate of Fisheries Research, Lowestoft, England, Reports #3 (1979) 36 pp; #4 (1980) 37 pp; #6 (1981) 32 pp; and #8 (1982) 35 pp. Concentrations of $^{239+240}Pu$, ^{241}Am and ^{238}Pu (other transuranics and other radionuclides) are reported in fish from the vicinity of the Irish Sea and in fish from other locations in the North Atlantic. This is a series of environmental reports of the Fisheries Radiobiology Laboratory and contains results too numerous to abstract herein. The reader is referred to these documents for specific concentrations in fish from different locations collected between 1977 and 1980.

Pu-46. Guary, J.C., and Fraizier, A., "Influence of Trophic Level and Calcification on the Uptake of Plutonium Observed, In Situ, In Marine Organisms," Health Phys. 32, 21 (1977). This work discusses the relationships between the concentration of plutonium in marine species and the trophic level of the respective organism. A decrease in the concentration of $^{239+240}Pu$ is evident from the results as the trophic level of the species increases.

Pu-47. Pillai, K.C., Dey, N.N., Mathew, E., and Kothari, B.U., "Behaviour of Discharged Radionuclides from Fuel Reprocessing Operations in the Aquatic Environment of Bombay Harbour Bay," Impacts of Nuclear Releases into the Aquatic Environment (Proc. Symp. Otaniemi 1975) IAEA, Vienna (1975), 277. Concentrations of $^{239+240}Pu$ are determined in several species of fish close-in and distant from the discharge location. Concentrations in fish muscle ranged from 0.0007 pCi/g wet offshore to 0.005 pCi/g in the bay. No CFs of plutonium in the organisms analyzed were reported.

Pu-48. Pillai, K.C., and Mathew, E., "Plutonium in the Aquatic Environment, Its Behaviour, Distribution and Significance," Transuranium Nuclides in the Environment, (Proc. Symp. San Francisco 1975) IAEA, Vienna (1976), 25. The plutonium concentrations in fish from Ref. Pu-47 are reproduced and again discussed in this report.

Table 1. Reported concentration factors for plutonium and americium in fishes from regions of the world oceans.

Common name	Trophic[d] level	Year	Location	Total animal	Muscle	Bone	Liver	Viscera	Ref.
Pacific (Source--global fallout, reactor and disposal sites)									
					PLUTONIUM				
Bonito	V	1964	S. Calif.		3				Pu-1
Rockfish	III-IV	1977	Farallon Is., Calif.		12				Pu-2
Young anchovy	III	1971-75	Tokai-Mura, Japan	51		60	90	21	Pu-3
Flounder	III-IV	1971-75	Tokai-Mura, Japan		92				Pu-3
Pacific-Marshall Islands (Source--close-in and global fallout)									
Convict surgeon	II	1972	6 locations within Bikini Atoll		<20				
Surgeonfish	II	1972	3 locations within Bikini Atoll		<20		9000	780	Pu-7
Convict surgeon	II	1972	Runit Is., Enewetak			<20		18000[d]	Pu-7
Skipjack tuna	V	1972	Runit Is., Enewetak					740[d]	Pu-7
Goatfish	III	1972	Runit Is., Enewetak		1500				Pu-7
Snapper	IV	1973	Kwajalein Atoll					3400	Pu-7
Mullet	II	1976	Kwajalein Atoll		6	200		1183[a]	Pu-8
Mullet	II	1976	9 locations within Enewetak Atoll			147		3367[a]	Pu-8
Convict surgeon	II	1976	Enewetak Atoll		8 ± 3	190[b]	2470[b]	12850[b,c]	Pu-9
Mullet	II	1977	6 locations within Bikini Atoll		5 ± 4	416[b]	2080[b]	7170[b,c]	Pu-9
Mullet	II	1978	6 locations - 2 within Enewetak, 4 within Bikini		11 ± 5	262[b]	3406[b]	17703[b,c]	Pu-9
Convict surgeon	II	1978	4 locations within Bikini Atoll		10 ± 6	238[b]	3213[b]	16080[b,c]	Pu-9
Mullet - convict surgeon	II	1978	Ailuk Atoll		6 ± 5	500[b]	2500[b]	8620[b,c]	Pu-9
Goatfish	III	1978	Ailuk Atoll		99 ± 55				Pu-9
Mullet - convict surgeon	II	1978	Ailinginae Atoll		<11				Pu-9
Goatfish - groupers	III	1978	Ailinginae Atoll		328 ± 168				Pu-9
Jacks - snapper	IV	1978	Ailinginae Atoll		<31				Pu-9
Mackerel - tuna - shark	V	1978	Ailinginae Atoll		<17				Pu-9
Mullet - convict surgeon	II	1978	Likiep Atoll		<17				Pu-9
Goatfish	III	1978	Likiep Atoll		134 ± 82				Pu-9
Mullet - convict surgeon	II	1978	Rongelap Atoll		9 ± 5				Pu-9
Goatfish - grouper	III	1978	Rongelap Atoll		345 ± 238				Pu-9
Jacks - snappers	IV	1978	Rongelap Atoll		24 ± 21				Pu-9
Mackerel - tuna	V	1978	Rongelap Atoll		4 ± 2				Pu-9
Mullet - convict surgeon	II	1978	Rongerik Atoll		6 ± 3				Pu-9
Goatfish	III	1978	Rongerik Atoll		144 ± 117				Pu-9
Jacks - snapper	IV	1978	Rongerik Atoll		21 ± 12				Pu-9
Mackerel - tuna	V	1978	Rongerik Atoll		12				Pu-9
Mullet - convict surgeon	II	1978	Wotho Atoll		4 ± 2				Pu-9
Goatfish	III	1978	Wotho Atoll		190 ± 140				Pu-9
Snapper	IV	1978	Wotho Atoll		14 ± 12				Pu-9
Goatfish	III	1978	Bikini Atoll		<6				Pu-9
Snapper	IV	1978	Bikini Atoll		5 ± 3				Pu-9
					8 ± 5				Pu-9

Table 1. (Continued).

Common name	Trophic[d] level	Year	Location	Total animal	Muscle	Bone	Liver	Viscera	Ref.
Atlantic (Source--global fallout)					PLUTONIUM (continued)				
Blue shark	V	1970	Cape Hatteras, N.C.		4	21	175		Pu-21,22
Mako shark	V	1971	Cape Hatteras, N.C.		13	29			Pu-22
Dusky shark	V	1971	Cape Hatteras, N.C.			49			Pu-22
Blue fin tuna	V	1970	Cape Cod, Mass.		2	90			Pu-21,22
Blue fish	V	1969	Cape Cod, Mass.		5	570	26		Pu-21,22
Stripped bass	V	1970	Cape Cod, Mass.		4	160	14	36	Pu-21,22
Flounder	III-IV	1970	Cape Cod, Mass.		1	50	57	1060	Pu-21,22
Tautog	IV	1970	Cape Cod, Mass.			510	64	730	Pu-21,22
Atlantic (Source--reprocessing waste and global fallout)									
Plaice	III-IV	unk	Windscale area		30				Pu-37
Dab	III-IV	unk	Windscale area		36				Pu-37
Salmon	III-IV	unk	Windscale area		1				Pu-37
Plaice	III-IV	8/75	Windscale area		<1				Pu-38
Plaice	III-IV	2/76	Windscale area		0.09	4.1	8.5	9.2[c]	Pu-39
Plaice	III-IV	5/76	Windscale area		0.42	57.8	16.9	35.7[c]	Pu-39
Plaice	III-IV	8/76	Windscale area		0.12	2.6	3.8	37.8[c]	Pu-39
Plaice	III-IV	11/76	Windscale area		0.04	1.8	2.4	16.4[c]	Pu-39
Plaice	III-IV	1975	La Hague, France	239	8	19	41	4942[c]	Pu-41
Blenny	IV	1974-75	La Hague, France	73					Pu-40
Mackerel	V	1974-75	La Hague, France	20					Pu-40
				15					Pu-40
Atlantic (Source--reprocessing waste)					AMERICIUM				
Plaice	III-IV	8/75	Windscale area		5				Pu-38
Plaice	III-IV	2/76	Windscale area		0.42	25	104	44[c]	Pu-39
Plaice	III-IV	5/76	Windscale area		0.90	178	102	96[c]	Pu-39
Plaice	III-IV	8/76	Windscale area		0.05	32	74	194[c]	Pu-39
Plaice	III-IV	11/76	Windscale area		0.88	28	74	159[c]	Pu-39

[a] Includes liver.
[b] Estimated from average tissue concentration ratios provided in Ref. Pu-9.
[c] Does not include gut contents.
[d] Trophic level assignments are those provided by the reference or from "Fishes of the Pacific Coast of Canada", W.A. Clemens and G.V. Wilbey, Fisheries Res. Board of Canada, Bull. #68 (2nd Ed.) 1961.

Plutonium and ^{241}Am Concentrations in Marine Invertebrates from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Sites)

1. References containing field-derived concentration factors.

Pu-49. (See Ref. Pu-1). $^{239+240}$Pu was measured in the wet tissue of mussels (Mytilus californianus) collected from southern California in 1964. The average value of the CF for plutonium in the wet tissue was 260 ± 30.

Pu-50. (See Ref. Pu-3). Concentrations of $^{239+240}$Pu ranging from 0.032 to 0.26 pCi/kg wet wt. and concentration factors are reported for shellfish flesh, Cephalopoda and Crustacea obtained from the region offshore from the Tokai reprocessing facility.

2. Some additional references to fallout levels accumulated by Pacific invertebrates.

Pu-51. (See Ref. Pu-2). $^{239+240}$Pu was measured in pooled samples of polychaetes and bivalves collected at 900 m depth from the region of the Farallon Islands radioactive waste disposal site. Concentration of $^{239+240}$Pu in the benthic polychaetes was 0.9 ± 0.5 pCi/kg wet and in the bivalves the concentration was 5 ± 1 pCi/kg wet wt.

Pu-52. (See Ref. Pu-6). Concentrations of $^{239+240}$Pu and ^{238}Pu are reported in some sections of shrimp, squid, crab, coral, brittlestar, seapen, snail, barnacle, sea cucumber, anemone, starfish and worms collected from different depths within the Farallon Islands radioactive waste disposal region. Viscera from sea cucumbers contained 80 ± 20 pCi/kg dry of $^{239+240}$Pu at the deep station and 1020 ± 80 pCi/kg dry at the shallow site.

Pu-53. Goldberg, E.D., Bowen, V.T., Farrington, J.W., Harvey, G., Martin, J.H., Parker, P.L., Risebrough, R.W., Robertson, W., Schneider, E., and Gamble, E., "The Mussel Watch", Envir. Conservation 5, 101 (1978). Concentrations of $^{239+240}$Pu, ^{238}Pu and ^{241}Am are reported in the meat and some shell of mussels and oysters collected during 1976 from the east, west and gulf coastal waters of the

United States. The west coast series of M. californianus samples is different from the east and gulf coast series of molluscus. The mean total $^{239+240}Pu$ is almost doubled, and the ^{241}Am: $^{239+240}Pu$ ratio is about tenfold higher on the west coast. Concentrations of $^{239+240}Pu$ in soft parts of east and gulf coast bivalves ranged from 0.08 to 0.29 dpm/kg wet weight and averaged 0.19 dpm/kg wet.

Pu-54. Koide, M., Lee, Dong Soo, and Goldberg, E.D., "Metal and Transuranic Records in Mussel Shells, Byssal Threads and Tissues", Estuar. Coast. Shelf Sci. 15, 679-695 (1982). Concentrations of $^{239+240}Pu$, ^{238}Pu and ^{241}Am are reported in the soft parts, byssal threads and shells of Mytilus edulis and Mytilus californianus collected from west coast locations between 1976 and 1979. The authors suggest that byssal threads offer advantages for transuranic nuclide monitoring. Concentrations of $^{239+240}Pu$ and ^{241}Am are from 3.5 to 4.4 times higher in the shell than in the soft tissue.

Pu-55. Goldberg, E.D., Koide, M., Hodge, V., Flegal, A.R., and Martin, J. "U.S. Mussel Watch: 1977-1978 Results on Trace Metals and Radionuclides", Estuar. Coast. Shelf Sci. 16, 69-93 (1983). The results of the U.S. Mussel Watch Monitoring Program for the period 1976-1978 for $^{239+240}Pu$, ^{238}Pu and ^{241}Am in bivalves are presented. Off the California coast, mussels show markedly elevated Pu concentrations in areas adjacent to the most intensive upwelling zones. Concentrations in mussels from Pacific coastal regions sampled in 1977 and 1978 ranged from 0.3 to 14 dpm/kg dry weight; in gulf coast oysters the range in concentration was from 0.3 to 2.3 dpm/kg; and in 1978, the concentration ranged from 0.4 to 2.7 dpm/kg in east coast bivalues .

B. Central Pacific Atolls and Other Locations Possibly Affected (Source Term--Local Fallout from the Pacific Nuclear Test Series)

1. References containing field-derived concentration factors.

No reported values.

2. Some additional references to Pu and ^{241}Am levels in invertebrates from Pacific Atolls.

Pu-56. (See Ref. Pu-10). $^{239+240}$Pu was measured in some body tissues of clams and sea cucumbers collected from Guam, Palau and Saipan between 1956-1959. Concentrations in the entire soft parts of giant clams range from 24 to 260 pCi/kg wet. Pu was most highly concentrated in the liver of the clam followed by, in order of decreasing concentrations, the gonad, mantle and muscle.

Pu-57. (See Ref. Pu-12). Concentrations of $^{239+240}$Pu and ^{241}Am (when detected by gamma spectrometry) are reported in tissues of Tridacna clams, in samples of eviscerated whole and viscera of sea cucumbers, spiny lobster, pencil urchins and top snails collected at Enewetak Atoll during the 1972 survey. Concentrations are also reported in Tridacna collected from Kwajalein Atoll.

Pu-58. (See Ref. Pu-14). $^{239+240}$Pu and ^{241}Am levels in Tridacna, sea cucumber and lobster samples from Enewetak Atoll are reported.

Plutonium and ^{241}Am Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for plutonium and americium.

Pu-59. (See Ref. Pu-21). Concentrations of $^{239+240}$Pu are reported in the bodies of mussels, clams and starfish collected from Cape Cod, MA, during 1970; CFs for $^{239+240}$Pu in the body and shell of the organisms are computed.

Pu-60. (See Ref. Pu-22). This paper reviews available concentration data through 1971 for plutonium in marine invertebrates. CFs are compiled for a variety of near shore organisms.

Pu-61. Noshkin, V.E., Bowen, V.T., Wong, K.M., and Burke, J.C., "Plutonium in North Atlantic Organisms; Ecological Relationships," Radionuclides in Ecosystems in Proceedings of the Third National Symposium on Radioecology, D.J. Nelson, Ed., United States Atomic Energy Commission, Washington, D.C., Conf-710501-P1(1973), 681. Concentrations of $^{239+240}$Pu are reported in a number of near shore invertebrates including mussels, clams, oysters, scallops, whelks, moon-shells, starfish, brittle stars, polycheate worms and sponges from the vicinity of Cape Cod, MA. CFs for $^{239+240}$Pu are computed. Concentrations ranged from 400 dpm/100 kg (wet weight) in samples of sponge to 2 dpm/100 kg in the adductor muscle of scallops.

Pu-62. (See Ref. Pu-23). Concentrations of $^{239+240}$Pu in the flesh and shells of several marine invertebrates are presented along with some ^{241}Am determinations. The samples were collected between 1970 and 1974 from the vicinity of Cape Cod, MA. CFs are computed for plutonium only. Concentrations of ^{239,240}Pu ranged from 0.3 dpm/kg wet weight in soft parts of the scallop, Spisula, to 3.3 dpm/kg in whole body of the starfish, Asterias.

Pu-63. (See Ref. Pu-26). The results presented in Ref. Pu-23 are reproduced with one additional measurement of ^{241}Am in the shell of a mussel. Several of the reported ^{241}Am values in the soft parts of mussel differ with the results reported in Ref. Pu-23.

Pu-64. Murray, C.N., and Fukai, R., "Measurement of $^{239+240}$Pu in the Northwestern Mediterranean", Estuar. Coast. Mar. Sci 6, 145 (1978). Measurements of $^{239+240}$Pu concentrations in whole body, shells, soft parts and pallial fluid from mussels collected from the northwestern Mediterranean coast are reported. Whole body concentrations ranged from 0.42 to 0.74 pCi/kg wet.

Pu-65. Guary, J.C., Higgo, J.J. W., Cherry, R.D., and Heyrand, M., "High Concentrations of Transuranics and Natural Radioactive Elements in the Branchial Hearts of the Cephalopod Octopus vulgaris", Mar. Ecol. Prog. Series 4, 123 (1981). Concentrations of ^{241}Am and $^{239+240}$Pu were determined in various tissues of Octopus vulgaris collected in the littoral zone off Monaco. Highest levels of ^{241}Am and $^{239+240}$Pu were found in the branchial hearts and the CF is computed to be 1×10^{4}. CFs in the reconstituted animal are for ^{241}Am and $^{239+240}$Pu, respectively, 2×10^{2} and 6×10^{1}.

Pu-66. Guary, J.C., Fowler, S.W., and Beasley, T.M., "Routes of Plutonium Uptake and Their Relation to Biomagnification in Starfish", Marine Poll. Bull. 14, 99 (1982). The concentrations of $^{239+240}Pu$ and ^{238}Pu are reported in Mediterranean and Cap de La Hague starfish collected in 1978. The natural tissue distribution of plutonium in starfish from a fallout contaminated environment was found to be identical to the distribution in starfish from the vicinity of a nuclear fuel reprocessing plant. CFs are provided for various body parts and whole animals from the Mediterranean.

2. Some additional references to fallout levels in invertebrates.

Pu-67. Livingston, H.D., Schneider, D.L., and Bowen, V.T., " ^{241}Pu in the Marine Environment by a Radiochemical Procedure", Earth Plant. Sci. Ltr. 25, 361 (1975). Concentrations of ^{238}Pu, $^{239+240}Pu$ and ^{241}Pu are reported in a starfishes (Asteries forbesi) collected in the area of Cape Cod, MA, during June 1970. Concentrations of $^{239+240}Pu$ and ^{241}Pu in the starfish were 2.1 and 17 dpm/kg wet, respectively. No CFs are reported.

Pu-68. (See Ref. Pu-24). The concentration of $^{239+240}Pu$ in the whole body of blue mussel collected from the Gulf of Finland in 1974 was 0.18 pCi/kg wet.

Pu-69. Livingston, H.D., and Bowen, V.T., "Americium in the Marine Environment-Relationships to Plutonium", Environmental Toxicity of Aquatic Radionuclides: Models and Mechanisms, M.W. Miller and J.N. Stannard, Eds., Ann Arbor Science Publ. Inc., Ann Arbor, Mich., (1976) 107. Americium to plutonium concentration ratios of 0.10 to 0.29 are reported in starfish, winkle shells and green urchin spines collected from the Massachusetts coast.

Pu-70. (See Ref. Pu-27). Concentrations of $^{239+240}Pu$ measured in parts of mussels, clams, starfish, sea urchins, lobsters and blood worms from the Southern Hemisphere are reported. No CFs are computed.

B. Environments Contaminated with Local Inputs (Source Term--Close-In Fallout, Non-Nuclear, Thule, Greenland)

1. References with field-derived concentration factors.

Pu-71. (See Ref Pu-33). $^{239+240}$Pu concentrations and some ^{238}Pu: $^{239+240}$Pu concentration ratios are shown for several bivalves and crustaceans collected from regions of Thule, Greenland, during August 1968. The CFs of $^{239+240}$Pu in bivalves and crustacea are reported.

2. Additional references to ^{239}Pu and ^{241}Am in invertebrates from this non-nuclear source.

Pu-72. (See Ref. Pu-34). Concentrations of $^{239+240}$Pu in the soft parts and shells of different mollusks and in soft parts of snails collected at Thule during 1974 are reported in a series of tables. Concentrations measured in brittle stars, starfish and worms are discussed.

Pu-73. (See Ref. Pu-35). Concentrations of $^{239+240}$Pu in worms, bivalves, brittle stars, and shrimps collected during 1968, 1970, and 1974 from regions of Thule, Greenland, are summarized.

Pu-74. (See Ref. Pu-36). The concentrations of ^{239}Pu and ^{241}Am are reported for a variety of benthic organisms collected at Thule during 1979. Concentrations of ^{239}Pu in the flesh of benthic worms ranges from 980 pCi/kg at the site of impact to 230 pCi/kg at a distance of 0.8 km from the point of impact.

C. Environments Contaminated with Local Inputs (Source Term--Reprocessing Wastes)

1. References with field-derived concentration factors

Pu-75. (See Ref Pu-37). $^{239+240}$Pu concentration factors for the soft part of the mussel, Mytilus edulis, from the Windscale vicinity are reported as 2×10^3. The CF for $^{239+240}$Pu in the soft part of winkles is also 2×10^3.

Pu-76. (See Ref. Pu-40). Concentrations of $^{239+240}Pu$ are measured in a number of invertebrates collected from a coastal site near the La Hague reprocessing facility. CFs for $^{239+240}Pu$ are computed.

Pu-77. (See Ref. Pu-41). The distribution of $^{239+240}Pu$ among the tissues of the crab, Cancer pagurus, is tabulated and the CF for the $^{239+240}Pu$ in the tissues is computed.

2. Some additional references to $^{239+240}Pu$ and ^{241}Am concentrations in invertebrates.

Pu-78. (See Ref. Pu-44). Concentrations of $^{239+240}Pu$, ^{238}Pu and ^{241}Am are reported in shellfish from the vicinity of Windscale and at commercial landings in the northeastern Irish Sea.

Pu-79. Pentreath, R.J., Jefferies, D.F., Lovett, M.B., and Nelson, D.M., "The Behaviour of Transuranic and Other Long-Lived Radionuclides in the Irish Sea and its Relevance to the Deep Sea Disposal of Radioactive Wastes", Marine Radioecology (Proc. 3rd NEA Sem. Tokyo 1979), OECD, Paris (1980), 203. Concentrations of $^{239+240}Pu$, ^{238}Pu and ^{241}Am in tissues of starfish and echinoids collected close to Windscale during 1978 are tabulated. The enchinoderm organs are enriched with ^{241}Am relative to plutonium.

Pu-80. Pentreath, R.J., "The Biological Availability to Marine Organisms of Transuranium and other Long-Lived Nuclides", Impacts of Radionuclide Releases Into the Marine Environment (Proc. Symp. Vienna 1980) IAEA Vienna (1981), 241. ^{241}Am and $^{239+240}Pu$ concentrations are compared in tissues of the Norway lobster (Nephrops norvegicus) from the Irish Sea and in claw and tail muscle of Homarus gammarus from the Windscale area. The author also reviews much of the literature related to the biological availability of transuranic radionuclides to marine vertebrates and invertebrates.

Pu-81. (See Ref. Pu-45). These reports contain monitoring data for $^{239+240}Pu$ and ^{241}Am levels in a variety of marine invertebrates from the vicinity of the Irish Sea and from other locations in the North Atlantic. Samples were collected for analysis between 1977 and 1980.

Pu-82. Pentreath, R.J., "The Use of Isotopic Ratios in Determining the Relative Biological Availabilities of Transuranium Elements" Techniques for Identifying Transuranic Speciation in Aquatic Environments (Proc. Meeting Ispra 1980) IAEA Vienna (1981), 141. ^{241}Am and $^{239+240}Pu$ concentrations are compared in samples of limpets, sea urchins and lobsters collected from regions near Windscale in 1978 and 1979. Curium and neptunium concentrations are also presented.

Pu-83. (See Refs. Pu-47 and Pu-48). Concentrations of $^{239+240}Pu$ in tissues of crab and arca from regions of Bombay Harbour are tabulated. Samples were collected between 1970 and 1974.

Table 2. Reported concentration factors for plutonium and americium in invertebrates from regions of the world oceans.

Common and/or scientific name	Year	Location	Whole animal	Soft tissue	Shell	Flesh	Ref.
			PLUTONIUM				
PORIFERA							
Sponge, Clathria delicata	1970	Cape Cod, Mass.	2100				Pu-60,61
Hymeniacidon sanguinea	1974-75	La Hague, France	1495				Pu-76
Halichondria panicea	1974-75	La Hague, France	1365				Pu-76
Reneira sp.	1974-75	La Hague, France	1260				Pu-76
ANNELIDA							
Marine worm(?)	1970	Cape Cod, Mass.	4100				Pu-60,61
Nereis diversicolor	1974-75	La Hague, France	315				Pu-76
Arenicola marina	1974-75	La Hague, France	103				Pu-76
COELENTERATA							
Actinia equina	1974-75	La Hague, France	165				Pu-76
Tealia felina	1974-75	La Hague, France	165				Pu-76
MOLLUSCA							
Cephalopoda	1971-75	Tokai, Japan	200				Pu-50
Octopus vulgaris	--	Monaco	60			8	Pu-65
Gastropoda							
Whelk, Busycon corita	1970	Cape Cod, Mass.		140	300		Pu-60,61
Moonshell, Lunatia heros	1970	Cape Cod, Mass.		660	690		Pu-60,61
Busycon	1970	Cape Cod, Mass.		400	570		Pu-62,63
Busycon	1972	Cape Cod, Mass.		300	2330		Pu-62,63
Buccinum	1974	Cape Cod, Mass.		750	520		Pu-62,63
Lunatia	1974	Cape Cod, Mass.		690			Pu-62,63
Winkles, Littorina littorea	--	Irish Sea		2000			Pu-75
Littorina littorea	1974-75	La Hague, France	205	333	178		Pu-76
Limpet, Patella vulgata	1974-75	La Hague, France	48	55	43		Pu-76
Nucella lapillus	1974-75	La Hague, France	70	85	68		Pu-76
Pelecypoda							
Mussel, M. californianus	1964	S. California		260 ± 30			Pu-49
Mussel, M. edulis	1970	Cape Cod, Mass.		300 ± 30	490		Pu-59,60,61
Mussel, Modiolus modiolus	1970	Cape Cod, Mass.		490			Pu-59,60,61
Clam, Mya arenaria	1970	Cape Cod, Mass.		440			Pu-59,60,61
Oyster, Ostrea virginica	1970	Cape Cod, Mass.		130 ± 30			Pu-60,61
Scallop, Pecten irradiaus	1970	Cape Cod, Mass.		520 ± 200	600	24 ± 19	Pu-60,61
Spisula	1973	Cape Cod, Mass.		270	20		Pu-62,63
Mussel, M. edulis	1971	Cape Cod, Mass.		440			Pu-62,63
Mussel, M. edulis	1971	Cape Cod, Mass.		490	810		Pu-62,63

Table 2. (Continued)

Common and/or scientific name	Year	Location	Whole animal	Soft tissue	Shell	Flesh	Ref.
			PLUTONIUM (continued)				
Mussel, M. edulis <5.4 cm	1975	Cape Cod, Mass.		410	1250		Pu-62,63
Mussel, M. edulis 5.4-7.5 cm	1975	Cape Cod, Mass.		410	123		Pu-62,63
Mussel, M. edulis >7.5 cm	1975	Cape Cod, Mass.		420	13		Pu-62,63
Mussel, M. gallo provinciales	1973	N.W. Mediterranean		180			Pu-64
Mussel, M. edulis	--	Irish Sea		2000			Pu-75
Bivalves (number of species)	1968	Thule		3500			Pu-70
Shellfish (?)	1971-75	Tokai, Japan		200			Pu-50
ARTHROPODA							
Crustacea							
Shrimp, crab	1971-75	Tokai, Japan	250				Pu-50
Shrimp	1968	Thule, Greenland	750				Pu-70
Crab, Carcinus magnas	1974-75	La Hague, France	90				Pu-76
Crab, Cancer pagurus	1974-75	La Hague, France	38				Pu-76
Lobster, (Homarus vulgaris)	1974-75	La Hague, France	60				Pu-76
Crab, (Cancer pagurus)	1975	La Hague, France	269		172	40	Pu-77
Balanus	1975	Cape Cod, Mass.	2520				Pu-62,63
Balanus	1975	Cape Cod, Mass.	1140				Pu-62,63
Balanus balanoides	1974-75	La Hague, France	303				Pu-76
ECHINODERMATA							
Ophiuroidea							
Brittle star	1970		760				Pu-60,61
Asteroidea							
Starfish Asterias forbesi	1970	Cape Cod, Mass.	1020				Pu-60,61
Coscinasteris tenuispina	1978	Mediterranean	2700				Pu-66
Marthasteris glacialis	1979	Mediterranean	2200				Pu-66
Asterias	1972	Cape Cod, Mass.	1830				Pu-62,63
Asterias	1972	Cape Cod, Mass.	2750				Pu-62,63
Asterina gibbosa	1974-75	La Hague, France	452				Pu-76
			AMERICIUM				
MOLLUSCA							
Cephalopoda							
Octopus vulgaris	--	Monaco	200			100	Pu-65

Cesium-137 Concentrations in Marine Fish from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{137}Cs and/or stable cesium.

Cs-1. Jenkins, C.E., "Radionuclide Distribution in Pacific Salmon," Health Phys. 17, 507 (1969). Concentrations of ^{137}Cs were measured in muscle tissue, liver and roe of 4 different species of Pacific salmon collected from Alaskan and Washington coastal regions between July and September 1967. Concentrations in muscle ranged from 54 to 209 dpm/kg wet wt. CFs for ^{137}Cs are reported.

Cs-2. Folsom, T.R., Young, D.R., and Sreekumaran, C., "An Estimate of the Response Rate of Albacore to Cesium", Symp. on Radioecology, D.J. Nelson and F.C. Evans, Eds., United States Atomic Energy Commission, Washington, D.C., Conf. 670503 (1969) 337. Natural and radioactive cesium levels in the flesh of albacore collected from the northeastern Pacific during 1965 and 1966 are provided. The mean concentration in muscle was 90 ± 18 pCi/kg wet wt. The accumulation factor for ^{137}Cs by fish muscle is 103 ± 7 and the value for stable cesium is 106 ± 4.

Cs-3. Young, D.R., and Folsom, T.R., "Cesium Accumulation in Muscle Tissue of Marine Fishes, Health Phys. 37, 703 (1979). Mean concentrations of stable cesium and corresponding concentration factors in white muscle tissue of four teleost fishes collected from the Gulf of California in 1968 are tabulated. The average concentration factor is 141±14.

Cs-4. Suzuki, Y., Nakamura, R., and Ueda, T., "Cesium-137 Contamination of Marine Fishes from the Coasts of Japan", J. Radiat. Res. 14, 382 (1973). The accumulation of ^{137}Cs by fishes from seawater was studied for eight years (1963-1970). In 1970, the level of ^{137}Cs in fish muscle was reduced to 8.7% (6.9 pCi/kg wet) of the peak value (79.9 pCi/kg) in 1963. Computed concentration factors for a variety of species ranged from 11 to 81. The concentration factors for stable cesium remained in a narrow range between 34 and 52. A seawater concentration of 0.5 µg/ℓ was used to compute concentration factors for stable cesium.

Cs-5. Ichikawa, R., and Ohno, S., "Levels of Cobalt, Cesium and Zinc in Some Marine Organisms in Japan", Bull. Japan Soc. Scient. Fisheries 40, 501 (1974). The CF computed for stable cesium in fish muscle was 20. A water concentration of 0.5 µg/ℓ was used to compute the CF. The CF for stable cesium in skin, liver and bone was 30.

Cs-6. Noshkin, V.E., Robison, W.L., and Harrison, F.L., Radiological Dose to Man Through the Marine Pathway from Reactor Operations at Humboldt Bay, California, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52160 (1976), 25 pp. ^{137}Cs concentrations are reported for the flesh of Dover sole collected from the bay during 1972 and 1973. The mean concentration during the period was 9 ± 2 pCi/kg wet weight (range 6-11 pCi/kg) and the computed CF is 38 ± 7.

Cs-7. (See Ref. Pu-3). The range and average concentrations of ^{137}Cs (pCi/kg wet wt.) are reported for whole Shirasu; (range 3.9 to 11.1; mean 5.7), the flesh of adult fish (range 1.6 to 12.4; mean 7.5); shellfish flesh; cephalopoda flesh; and whole crustacea obtained between 1971 and 1975 from the coastal ocean offshore at Tokai, Japan. CFs are computed for ^{137}Cs.

Cs-8. (See Ref. Pu-2). The concentration of ^{137}Cs in the muscle of rockfish collected during 1977 near the Farallon Islands is reported as 17 ± 2 pCi/kg wet wt. The CF for ^{137}Cs is 86 ± 10.

Cs-9. Nakahara, M., Ueda, T., Suzuki, Y., Ishii, T., and Suzuki, H., "Concentration Factors of Mesopelagic Organisms", Marine Radioecology (Proc. 3rd NEA Sem., Tokyo 1979) OECD, Paris (1980), 323. The levels of fallout ^{137}Cs were determined in the flesh of mesopelagic and coastal fishes. The average concentration of ^{137}Cs in the flesh of the mesopelagic fishes (18.7 ± 10.7 pCi/kg wet) was comparable to the average concentration in coastal fishes (18.1 ± 14.7 pCi/kg wet). The authors estimate a CF for ^{137}Cs in the fish muscle at about 100 using surface seawater concentrations for comparative purposes. The mean CF for stable cesium in the flesh of fish was 60 and in cephalopod the value was 10 using 0.5 µg/ℓ as the average seawater concentration of stable cesium. The mesopelagic fish caught and analyzed for ^{137}Cs include: Sebastes mastsubarai, Scombrops boops, Hyperoglyphe japonica, Paracaesio caeruleus and Beryx splendens.

Cs-10. Izak-Biran, T., and Guinn, V.P., "Determination of Cesium and Potassium in Marine Species by Neutron Activation Analysis", J. Radioanal. Chem. 55, 61 (1980). Stable cesium levels were determined in muscle tissues of squid, dover sole, albacore and bocaccio. Accumulation factors for cesium in muscle tissues are computed.

2. Some additional references to fallout levels in Pacific fish; no reported CFs.

Cs-11. Folsom, T.R., and Hodge, V.F., "Early Surveillance Around Coastal Nuclear Installations", Environmental Surveillance Around Nuclear Installations, (Proc. Symp. Warsaw 1973) IAEA, Vienna SM-180 (1974), 289. Concentrations of ^{137}Cs are compared to ^{40}K in the various tissues and organs of Thunnus alalunga. The parallel behavior of these two nuclides suggests the usefulness of potassium for normalizing biological samples to be assayed for traces of radiocesium.

Cs-12. (See Ref. Pu-5). Concentrations of fallout ^{137}Cs in the liver, muscle and blood of Pacific albacore collected from regions west of California between 1964 and 1977 are provided. Concentrations in muscle ranged from a high of 355 dpm/kg in 1964 to a low of 51 dpm/kg in 1976.

Cs-13. Fukai, R., and Yamagata, N., "Estimation of the Levels of ^{137}Cs in Sea-water by the Analysis of Marine Organisms", Nature 194, 466 (1962). Ratios of ^{137}Cs to stable cesium are reported for a number of marine organisms collected from the Western Pacific during 1960-1961.

Cs-14. Held, E.E., "Fallout Radionuclides in Pacific Ocean Tuna", Radionuclides in Ecosystems (Proc. Symp. Oak Ridge 1971) D.J.Nelson, Ed., United States Atomic Energy Commission, Washington, D.C., Conf. 7100601-II (1973) 689. The paper shows results obtained from analysis of Pacific tuna collected in 1967, 1968, and 1969. The occurrence of ^{60}Co and ^{137}Cs as well as ^{55}Fe is discussed. The average ^{137}Cs concentration in the light muscle of tuna caught north of the equator was 0.15 pCi/g dry, with a range from background to 0.43 pCi/g. Tuna caught near Bikini Atoll contained the same average ^{137}Cs concentration (0.16 pCi/g; range, background to 0.31 pCi/g) as other tuna caught north of the equator.

Cs-15. (See Ref. Pu-4). Fallout levels of ^{137}Cs were determined in the liver and muscle of albacore tuna collected between 1964 and 1971 from S. California waters. The ^{137}Cs level in liver ranged from 0.2 to 3 pCi/kg wet and in muscle samples the concentration ranged from 58 to 160 pCi/kg. From the results, the authors estimate that the half-time of residence for ^{137}Cs in the upper layer of the north Pacific is 17 years.

Cs-16. Kujala, N.F., Larsen, I.L., and Osterberg, C.L., "Radioisotope Measurements of the Viscera of Pacific Salmon", Symp. on Radioecology, E.J. Nelson and F.C. Evans, Eds., United States Atomic Energy Commission, Washington, D.C., CONF-670503, 1969, 440. Although no data are provided, the authors note that ^{137}Cs appeared in three Canadian coho salmon samples (<0.50 pCi/g) and suggest that coho, like chinook, feed at a higher trophic level. Salmon that feed more on plankton such as the sockeye, pink and chum did not seem to concentrate ^{137}Cs.

Cs-17. (See Refs. Pu-6 and Pu-52). ^{137}Cs was determined in some sections of pelagic fish and benthic organisms collected near the Farallon Islands radioactive waste disposal site. The range in ^{137}Cs concentrations measured in samples of viscera, skin, liver, G.I. tract contents and whole body was between 0.09 and 0.45 pCi/g dry wt. ^{137}Cs was below detection limits in all muscle tissue samples processed.

Cs-18. Saiki, M., "Marine Radioecological Studies in Japan", Seminar on Marine Radioecology in Proc. of the Seminar on Marine Radioecology, Cherbourg, 3-6 Dec. 1968 (European Nuclear Energy Agency, Paris) (1969), 77. Fallout ^{137}Cs concentrations in the muscle and viscera of several species of marine, brackish and freshwater fish collected from the Sea of Japan between 1963 and 1966 are reported. Concentrations of ^{137}Cs in muscle during this period ranged from 4.6 to 188 pCi/kg wet weight.

Cs-19. Ueda, T., Suzuki, Y., and Nakamura, R., "Transfer of ^{137}Cs and ^{90}Sr from the Environment to the Japanese Population via Marine Organisms", Population Dose Evaluation and Standards for Man and His Environment, (Proc. Sem. Portoroz 1974) IAEA, Vienna (1974), 501. Data show the total mean concentration of ^{137}Cs in muscle of fishes (collected between 1964 and 1970) from the waters of Japan together with levels in seawater collected from the same region. No regional variation in the concentration of ^{137}Cs was evident

in fish muscle. The level in fish muscle was 80 pCi/kg wet in 1963 and decreased to 7 pCi/kg by 1970. Correlations between level and habitat were not apparent from the data.

Cs-20. Young, D.R., Folsom, T.R., and Hodge, V.F., "^{137}Cs and ^{40}K in the Flesh of Pacific Albacore, 1964-1974", Health Phys. 29, 689 (1975). Between 1965 and 1974 the average concentration of ^{137}Cs in Pacific albacore muscle decreased steadily from 90 to approximately 40 pCi/kg wet. The authors use this information to suggest that the effective half-time for ^{137}Cs in the upper layer of the eastern North Pacific is about one decade. The 1965 mean concentrations in albacore flesh from four widely separated fisheries in the Northern Hemisphere agreed to within a factor of two, ranging from 50 to 90 pCi/kg wet. Specimens from the South Pacific fisheries based at American Samoa during this period average only 14 pCi/kg wet.

Cs-21. Nelson, V.A., and Seymour, A.H., Amchitka Radiobiological Program Progress Report January 1975, prepared for the United States Atomic Energy Commission Nevada Operations Office, Las Vegas, NV, NVO-269-27 (1976) 47pp. ^{137}Cs concentrations in the flesh and liver of halibut collected off Amchitka Island between 1971 and 1975 are given. Concentrations in flesh range between 0.06 and 0.11 pCi/g dry. Greenling collected during the same period had similar concentrations of ^{137}Cs associated with muscle tissue.

B. Central Pacific Atolls and Locations Possibly Affected (Source Term--Local Fallout from the Pacific Nuclear Test Sites)

1. References containing field-derived concentration factors for ^{137}Cs.

Cs-22. (See Ref. Pu-8). The CF for ^{137}Cs in the muscle tissue of a snapper collected in 1975 from Kwajalein Atoll was 89 ± 11. The concentration of ^{137}Cs in muscle tissue was 11.9 ± 1.5 pCi/kg wet wt.

2. Additional references to ^{137}Cs concentrations in fish from Pacific atolls; no concentration factors provided.

Cs-23. Held, E.E., Radiological Resurvey of Animals, Soils and Groundwater at Bikini Atoll, 1969-70, prepared for the U.S. Atomic Energy Commission Nevada Operations Office, Las Vegas, NV, NVO-269-8 Rev. 1 (1971) 44 pp.

Concentrations of ^{137}Cs were measured in samples of reef fish collected from different regions of Bikini Atoll in 1969 and 1970. In 1969, concentrations in eviscerated whole reef fish ranged from 0.12 to 1.12 pCi/g dry wt.

Cs-24. Lowman, F.G., "Radionuclides in Pacific Plankton and Tuna", Radioecology (Proc, Symp. Fort Collins, Colo. 1961) V. Schultz and A.W. Klements Jr., Eds., Reinhold Publ. Corp., NY (1963), 145. The author indicates that ^{137}Cs makes up, at the most, 1.1% of the total fission and activation product radioactivity in muscle of tuna collected at Enewetak in 1958.

Cs-25. Lynch, Jr., O.D.T., McCraw, T.F., Nelson, V.A., and Moore, W.E., Radiological Resurvey of Food, Soil, Air and Groundwater at Bikini Atoll, 1972, United States Energy and Research Development Administration, Washington, D.C., ERDA-34 (1975) 33pp. ^{137}Cs concentrations in the muscle, liver and viscera of several different species of fish collected from Bikini Atoll in May 1972 are reported. The range in concentrations detected in various fish from different area of the lagoon were: muscle tissue, 0.9 to 2.9 pCi/g dry; liver, 0.3 to 1.9 pCi/gm dry; and viscera, 0.1 to 1.4 pCi/g dry.

Cs-26. Nelson, V.A., Radiological Survey of Plants, Animals, and Soil at Five Atolls in the Marshall Islands, prepared for the U.S. Dept. of Energy, Nevada Operations Office, NVO-269-36 (1979) 33 pp. ^{137}Cs concentrations were determined in a few samples of fish collected from Rongelap and Wotje Atolls in 1976. The concentrations ranged from 0.04 to 0.10 pCi/g dry wt. in the parts analyzed.

Cs-27. (See Ref. Pu-16). Concentrations of ^{137}Cs are shown in various sections of different fish obtained from Christmas Island during 1975; from Rongelap, Utirik and Ailinginae Atolls in 1974; and from Bikini in December 1974 and April 1975. Levels in tissue of Bikini fish (0.1 to 4.5 pCi/g dry) exceeded those at the other atolls.

Cs-28. (See Ref. Pu-17). Measurements of ^{137}Cs were attempted in 31 sections of fish collected in Micronesia in November 1975. In 81% of the samples, the ^{137}Cs content was less than the two sigma propagated counting error. Results are expressed as pCi/g dry wt. The highest reported concentration of 0.59 ± 0.30 pCi/g dry was detected in the viscera of a goatfish from Ponape.

Cs-29. (See Ref. Pu-18). ^{137}Cs concentrations in a variety of dissected fish parts from different species collected during a 1978 survey of Rongelap, Utirik, Taka, Bikar, Rongerik, Ailinginae, Likiep, Jemo, Ailuk, Mejit, Wotho and Ujelang are shown. The atolls surveyed received different amounts (ranging from zero) of local fallout from the tests conducted at Bikini and Enewetak. All concentration data are expressed as pCi/kg wet wt. and dry/wet weight ratios are provided for conversion purposes. Average levels of ^{137}Cs in the flesh of all reef fish from the different atolls ranged from 6 to 24 pCi/kg wet wg; in lagoon pelagic species the range was from 16 to 28 pCi/kg. A table of comparative concentrations from other global locations is also shown and includes recent measured concentrations in U.S. and foreign market fish samples.

Cs-30. (See Ref. Pu-19). This report discusses the presence of ^{113m}Cd in marine organisms from Pacific Atolls but includes some concentrations of ^{137}Cs in fish liver samples for comparative purposes. Concentrations of ^{137}Cs in liver from the different fishes ranged from .003 to 0.57 pCi/g dry wt.

Cs-31. (See Ref. Pu-20). As in reference Cs-30, the discussion centers on ^{113m}Cd concentrations but includes measurements of ^{137}Cs in selected samples from Pacific Atolls and in mullet from North Carolina. Results are expressed in pCi/g dry weight but dry/wet weight ratios are provided for conversion purposes. Fallout ^{137}Cs in the muscle of mullet from Beaufort, North Carolina, was 0.033 pCi/g dry while the level in fish muscle from Enewetak ranged from 0.18 to 1.76 pCi/g dry.

Cs-32. (See Refs. Pu-12 and Pu-57). This is a summary and partial discussion of the results from a radiological survey of Enewetak Atoll conducted in 1972-1973. Concentrations of ^{137}Cs are reported in tissues and organs from a variety of reef and l[illegible]n pelagic species collected from different locations within the lagoon. In ad[illegible]ion, fish were also obtained from Kwajalein Atoll, considered to be a control site [illegible] contaminated with radionuclides from local fallout, for ^{137}Cs analysis. All [illegible]lts are expressed in terms of dry weight of tissues analyzed but wet/dry we[illegible] ratios are provided for conversion to wet weight. CFs are not provided but ca[illegible] determined using concentrations listed in the report which were measured [illegible] the lagoon water from the vicinity where fish were collected.

Cs-33. Palumbo, R.F., Radionuclide Content of Foodstuffs Collected at Christmas Island and at other Islands of the Central Pacific during Operation Dominic, 1962, Laboratory of Radiation Biology, Univ. of Wash., Seattle, UWFL-87 (1963) 37pp. Concentrations of ^{137}Cs are reported in fish collected from several Pacific Atolls and islands including Canton, Christmas, Washington Island, Fiji, Palmyra, Penrhya, Rarotonga and Tongatapu before and after the 1962 test series.

Cs-34. Palumbo, R.F., Seymour, A.H., and Welander, A.D., "Radionuclides in Foods from the Central Pacific 1962, Nature 209, 1190 (1966). ^{137}Cs was measured in the light muscle of tuna collected between March and August 1962 from the vicinity of Christmas Island following the nuclear test series Dominic. Concentrations ranged between 10 and 80 pCi/kg wet. In addition, values are reported for tuna landed at Tokyo in 1962. Mean levels of ^{137}Cs were 30 pCi/kg, but concentrations as high as 240 pCi/kg were measured in light muscle tissue.

Cs-35. A.H. Seymour, Gamma-Emitting Radionuclides in Tuna Samples from the Tokyo Central Fish Market 1962, Laboratory of Radiation Biology, Univ. of Wash., Seattle, UWFL-90 (1963) 23 pp. Samples of tuna were obtained from the Tokyo Central Fish Market during the period from May 2 to Oct. 31, 1962, for radionuclide analysis. The fish were caught in the western Pacific Ocean by Japanese commercial fishermen before, during and after the U.S. nuclear testing program near Christmas Island in 1962. ^{137}Cs values are reported in the flesh, skin and bone of the samples analyzed. In 446 eviscerated tuna the concentration of ^{137}Cs in the light muscle of tuna averaged 28 pCi/kg wet; in the dark muscle, 48 pCi/kg; in skin, 62 pCi/kg and in bone, 38 pCi/kg. Samples caught within 700 miles of Christmas Island contained higher levels of ^{137}Cs.

Cs-36. (See Ref. Pu-10). Only two positive measurements of ^{137}Cs in fish flesh were recorded from an extensive number of analyses of fish collected between June 1956 and June 1957 from islands in the western Pacific. The level ranged from 1 to 6 x 10^{-7} μCi/g.

Cs-37. Welander, A.D., Bonham, K., Palumbo, R.F., Gessel, S.E., Jackson, F.G., McClin, R., and Lewis, G.B., Bikini-Enewetak Studies, 1964. Part II Radiobiological Studies, Laboratory of Radiation Biology, Univ. of Wash.,

Seattle, UWFL-93 (1967) 233 pp. ^{137}Cs concentrations are reported for a number of fish and invertebrate samples collected during a survey of Bikini and Enewetak in 1964. Mean concentrations for whole fish ranged from 0 to 6.3 pCi/g dry.

Cs-38. Welander, A.D., and Palumbo, R.F., Radionuclide Content of Oceanic Fish, Plankton, and Water in the Vicinity of Christmas Island, March through Aug. 1962, Laboratory of Radiation Biology, Univ. of Wash., Seattle, UWFL-88 (1963) 37 pp. ^{137}Cs was measured in light and dark muscle and liver of yellowfin, big eye, skip jack and marlin collected from the vicinity of Christmas Island between March and August 1962. The highest level of ^{137}Cs detected in muscle tissue was 180 pCi/kg wet wt.

Cs-39. (See Ref. Pu-11). Average levels of ^{137}Cs in fish (0.58 pCi/g dry wt.) and invertebrates collected during 1964 from Bikini and Enewetak Atolls are shown. No CFs are tabulated. Among the fish analyzed, omnivores had higher levels of ^{137}Cs than the carnivores, and fish that normally feed on invertebrates had higher concentrations than piscivores.

Cesium-137 Concentrations in Marine Fish from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{137}Cs and/or stable cesium

Cs-40. Agnedal, P.O., "Measurements of Background and Fallout Radioactivity in Samples from the Baltic Bay of Tavern 1957-1961", AE-171 (1965) 47 pp. This paper includes measurements of ^{137}Cs and ^{90}Sr in marine organisms collected from the Baltic Sea before 1963. A CF for ^{137}Cs in flounder is reported as 200 but the author states that the value used for the cesium content of water was uncertain.

Cs-41. Pentreath, R.J., "The Role of Food and Water in the Accumulation of Radionuclides by Marine Teleost and Elasmobranch Fish", Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle 1972) IAEA, Vienna (1973), 421. Analyses of stable Cs in plaice muscle indicate a CF of 54. In the North Sea direct measurement of the ^{137}Cs concentration factors for fish >25 cm long gives values of approximately 56. ^{137}Cs levels are also reported in the flesh of plaice (6.3 to 16 pCi/g wet) and skate (4.5 to 10.2 pCi/g wet) caught off Windscale between 1970 and 1971. Seawater concentrations during this period were approximately 330 pCi/ℓ.

Cs-42. Van As, D., Fourie, H.O., and Vleggaar, C.M., "Accumulation of Certain Trace Elements in Marine Organisms from the Sea Around the Cape of Good Hope", Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle 1972) IAEA, Vienna (1973), 615. Stable cesium was determined in the flesh from a variety of edible marine species including line-fish from commercial fisheries, white fish and pelagic fish. CF were computed by assuming a value of 0.34 µg/ℓ as the average concentration of cesium in seawater. Stable cesium CFs for fish muscle ranged from 18 to 132.

Cs-43. Gilat, E., Laichter, Y., and Shafrir, N.H., "Behaviour of ^{137}Cs in the Marine Environment", Impacts of Nuclear Releases into the Aquatic Environment (Proc. Symp. Otaniemi 1975) IAEA, Vienna (1975), 63. ^{137}Cs was measured in a number of marine fish and invertebrates from the Mediterranean Sea. Concentrations of ^{137}Cs in fish ranged from .018 to .102 pCi/g dry. No indication is provided as to what part of the fish was analyzed. It is assumed the results refer to the entire animal. Dry weight CFs are tabulated.

Cs-44. Feldt, W., Kanish, G., and Laurer, R., "Radioactive Contamination of the NEA Dumping Sites", Impacts of Radionuclide Releases Into the Marine Environment (Proc. Symp. Vienna 1980), IAEA, Vienna (1981), 465. A variety of marine samples was collected during 1979 and 1980 from three regions of the NEA dumping site. The authors report between 3.0 and 120 pCi/kg dry wt. of ^{137}Cs in various nekton organisms caught in the Atlantic. Benthic organisms contained between 7 and 270 pCi/kg dry wt. The nekton and benthic organisms collected for analysis are indicated in the paper. The CF for ^{137}Cs determined in the flesh of Macruridae (rat-tailed fish) was 150.

Cs-45. Dougherty, G., and Ng, C.E., "^{137}Cs and ^{40}K Levels in Marine Species Caught in Malaysian Waters", Health Phys. 43, 915 (1982). Fallout ^{137}Cs (11 to 250 pCi/kg dry) and natural ^{40}K concentrations are reported in several whole fish caught in Malaysian waters in 1980 and 1981. Dry wt. CFs are computed for ^{137}Cs using a value of 0.16 pCi/ℓ as the seawater concentration. This value was quoted for the Indian Ocean in a 1973 reference and may not be representative of 1980 concentrations.

2. Some additional references to fallout concentrations accumulated by Atlantic fish; no reported CFs.

Cs-46. Bakunov, N.A., "Concentration of ^{137}Cs in Commercial Fish of the Atlantic Ocean, Baltic and Caspian Sea", Radiobiology USSR (903) 14: 171 (1974) (71:2) (72: Issue 3) AEC-tr-7596, (1974) 171. From 4 to 14 pCi/kg were reported in herring, bass, hake, mackerel and swordfish from the Atlantic between October 1967 and December 1978. During this period, 51 to 87 pCi/kg was the range in concentration in herring, cod and eel from the Baltic Sea.

Cs-47. Feldt, W., "Measurement of Strontium 90 and Cesium 137 in Fishes", Proceedings of a Symp. on Nuclear Detonations and Marine Radioactivity, S.H. Small, Ed., Norwegian Defense Research Establishment, Kjeller, (1963), 105. ^{137}Cs concentrations in fish from the North Atlantic, Norwegian Sea, Barrents Sea, North Sea and Baltic Sea collected in 1961 and 1962 showed a marked dependency on water salinity. Species are not identified. Concentrations in fish, expressed as pCi/g of potassium, ranged from 5 to 20.

Cs-48. Feldt, W., "Radioactive Contamination of North Sea Fish", Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters (Proc. Symp. Vienna 1966), IAEA, Vienna (1966), 739. Cod, herring, haddock, redfish and other fish collected from the North Sea between 1963 and 1964 were analysed for ^{137}Cs. The distribution of ^{137}Cs within tissues of cod is presented. Fifty-three percent of the body burden of ^{137}Cs (110 pCi/kg whole fish) in cod was associated with the muscle tissue; 31% with the skin; 3% with the bone and gills; 4% with the stomach/intestine; 5% with the gonads; 0.8% with the liver and 0.2% with the spleen/heart. Concentration factors were not computed but water concentrations from the region where the fish were caught are given and estimates of CFs could be made.

Cs-49. Lowman, F.G., Phelps, D.K., McClin, R., Roman de Vega, V., Oliver de Padovani, I., and Garcia, R.J., "Interactions of the Environmental and Biological Factors on the Distribution of Trace Elements in the Marine Environment", Disposal of Radioactive Wastes into Seas, Oceans and Surface Waters, (Proc. Symp. Vienna 1966) IAEA, Vienna (1966), 249. Fallout levels of ^{137}Cs (0.15 to 0.22 pCi/g wet) were determined in the G.I. tract and gonad of marlin caught off the west coast of Puerto Rico. The authors comment that ^{137}Cs is found only in the highest trophic level organisms.

Cs-50. Lowe, B.G., "^{137}Cs and ^{40}K in the Flesh of Fish of the Indian Ocean and the Straits of Malacca", Health Phys. **36**, 723 (1979). Fallout ^{137}Cs (5 to 9.9 pCi/kg wet wt.) and natural ^{40}K concentrations were determined in the flesh of several fish caught in the Indian Ocean, 100 miles off Sumatra in 1976. Concentrations are reported as both pCi/kg wet and pCi/kg dry weight.

Cs-51. Ortins de Bettencourt, A., Vaz Carreiro, M.C., and Sequeira, M.M., "Contribution Au Controle Radiologique du Milieu Marin", Marine Radioecology (Proc. 3rd NEA Sem., Tokyo 1979) OECD, Paris (1980), 47. Fallout concentrations of ^{137}Cs are reported in the flesh of the scabbard fish (Aphanopus carbo) collected at depths of 1800 to 2000 m near Maderia Island in 1979. Concentrations ranged from 6.8 to 10.7 pCi/kg wet wt.

Cs-52. Preston, A., "Concentrations of ^{55}Fe in Commercial Fish Species from the North Atlantic", Mar. Biol. **6**, 345 (1970). Fallout ^{137}Cs concentrations in flesh of cod and plaice collected between 1963 and 1969 from Icelandic and North Sea fishing grounds ranged from <6 to 80 pCi/g wet.

Cs-53. Schelske, C.L., "Ecological Implications of Fallout Radioactivity Accumulated By Estuarine Fishes and Mollusks", Radionuclides in Ecosystems (Proc. Symp. Oak Ridge 1971) D.J. Nelson, Ed., United States Atomic Energy Commission, Washington, D.C., CONF-710501-II (1973) 791. Fallout radionuclides, including ^{137}Cs and ^{54}Mn, and naturally occurring ^{40}K were measured in estuarine organisms collected near Beaufort, North Carolina, between 1963 and 1966. CFs were not determined. ^{137}Cs levels ranged from 1.62 to 28.7 pCi/100 g wet wt.

Cs-54. Mitchell, N.T., and Pentreath, R.J. "Monitoring in the North-East Atlantic Ocean for the Dumping of Packaged Radioactive Waste", Radioactive Protection--Advances in Theory and Practice (Proc., 3rd Intern. Symp. of the Society for Radiological Prot., Inverness, 1982), Vol. 1, CONF-820613(1982) 120. ^{137}Cs concentrations in the muscles of the deep sea fish Corphaenoides (Nematonurus) armatus collected from the northeast Atlantic Ocean near the radiological dumpsite during 1980 ranged from 0.16 to 0.47 Bq/kg wet. The ^{137}Cs concentrations in the dumpsite fish were reported to be not significantly different from those specimens of the same species caught at other locations in the northeast Atlantic.

Cs-55. (See Ref. Pu-32). Concentrations of ^{137}Cs are reported in muscle and eviscerated whole deep sea fish collected in traps from 2100 m in the Bay of Biscay during 1981. The average fallout concentration in the different species was 5.1 ± 2.3 pCi/kg wet.

B. Coastal and Ocean Studies (Source term--Reprocessing Facilities Discharges)

1. References containing field-derived concentration factors for ^{137}Cs and stable Cs or both in fish from both the immediate vicinity and at distances from Windscale releases.

Cs-56. Bryan, G.W., Preston, A., and Templeton, W.L., "Accumulation of Radionuclides by Aquatic Organisms of Economic Importance in the United Kingdom," Disposal of Radioactive Wastes into Seas, Oceans and Surface Water (Proc. Symp. Vienna, 1966) IAEA, Vienna (1966), 623. CFs for stable cesium and potassium and ^{137}Cs are given for invertebrates and fish collected from the regions near Windscale. CFs for ^{90}Sr are also tabulated. In the flesh of marine fish the range in the CF for ^{137}Cs is from 24 to 62, and for ^{90}Sr the concentration factor is 0.3.

Cs-57. Preston, A., and Jefferies, D.F., "Aquatic Aspects in Chronic and Acute Contamination Situations," Environmental Contamination by Radioactive Materials (Proc. Symp. Vienna 1969) IAEA Vienna (1969), 183. Tables are provided showing average concentrations of naturally-occurring radionuclides in fish flesh and invertebrates and the average water concentrations. Concentrations of fallout ^{137}Cs in commercial fish caught from several oceanic

locations between 1963 and 1968 ranged from less than 6 to 80 pCi/kg wet wt. ^{137}Cs and ^{90}Sr levels in fish from the vicinity of Windscale between 1963 and 1966 are also provided. ^{137}Cs levels in the flesh of these fish during this period ranged from 0.5 to 1.0 pCi/g wet. CF for ^{137}Cs and ^{90}Sr in mollusks, crustacea and fish from the Windscale vicinity are computed.

Cs-58. Pentreath, R.J., and Jefferies, D.F., "The Uptake of Radionuclides by I-Group Plaice (Pleuronectes platessa) off the Cumberland Coast, Irish Sea", J. Mar. Biol. Ass. U.K. 51, 963 (1971). Changes in ^{137}Cs concentrations were followed in the flesh of plaice and in other environmental material from the Cumberland coast for a 7-month period during 1969. The ^{137}Cs flesh levels (18-37 pCi/g wet) were examined in conjunction with the fluctuations of the nuclide in seawater, sediment, and the fish gut contents. Of the three major dietary components found throughout the sampling period the calculated intake of ^{137}Cs from food appears to fluctuate most closely with the Nephtys fraction of the diet, despite its relatively low ^{137}Cs content. ^{137}Cs CFs are computed.

2. Additional references to ^{137}Cs concentrations in fish from both the immediate vicinity and at distances from Windscale releases.

Cs-59. (See Ref. Pu-45 and Pu-81). ^{134}Cs and ^{137}Cs concentrations are reported in fish from the Irish Sea vicinity and from collections made outside the region of Windscale between 1977 and 1980. Concentrations of ^{137}Cs in 1977, for example, range from 64 pCi/g wet in cod muscle from the Windscale shoreline to 0.01 pCi/gm in cod muscle from the Barents Sea.

Cs-60. Mauchline, J., and Taylor, A.M., "The Accumulation of Radionuclides by the Thornback Ray, Raia clavata l., in the Irish Sea", Limnol., Oceanol. 9, 303 (1964). ^{137}Cs levels in tissues and organs of the ray collected from an area at the end of the Windscale pipeline in 1961 are provided. Highest levels of cesium were in the cartilage (0.53 pCi/g wet) and stomach contents (0.56 pCi/g wet). The flesh (0.20 pCi/g wet) contained the lowest concentration of cesium.

Cs-61. Pentreath, R.J., Woodhead, D.S., and Jefferies, D.F., "Radioecology of the Plaice (Pleuronectes platessa L.) in the Northeast Irish Sea," Radionuclides in Ecosystems (Proc. Symp. Oak Ridge 1971) D.J. Nelson, Ed., United States

Atomic Energy Commission, Washington, D.C., CONF-710501-II (1973) 731. ^{137}Cs levels in the flesh and gut contents of plaice collected during 1968 and 1969 from regions near the Windscale pipeline are provided. Concentrations in flesh ranged from 0.7 to 4.1 pCi/g wet during this period while gut contents ranged from 1.2 to 7.2 pCi/g wet.

Cs-62. Mitchell, N.T., "Radioactivity in Surface and Coastal Waters of the British Isles," Ministry of Agriculture Fisheries and Food, Fisheries Radiobiology Laboratory, Hamilton Dock, Lowestoft, England Reports FRL1(1967); FRL2(1968); FRL5 (1969); FRL7(1971); FRL8(1971); FRL9(1973); FRL10(1975); FRL14(1978). This series of reports includes summaries of monitoring data for radionuclides sampled in various regions of the British Isles and from other vicinities. Data for ^{137}Cs in a variety of fish collected during the period 1966-1976 are presented.

Cs-63. Templeton, W.L., and Preston, A., "Transport and Distribution of Radioactive Effluents in Coastal and Estuarine Waters of the United Kingdom", Disposal of Radioactive Wastes into Seas, Oceans and Surface Water, (Proc. Symp. Vienna, 1966) IAEA, Vienna (1966), 267. Concentrations of ^{137}Cs found in the flesh (0.58 pCi/g wet) of plaice in the Windscale discharge area and concentrations in flesh (0.01 to 0.04 pCi/g wet) of fish collected at sites distant from the discharge are provided. The samples were collected in 1964. No CFs for ^{137}Cs are computed.

3. References containing field-derived concentration factors for ^{137}Cs in fish from the vicinity of the Bhabha Atomic Research Center, Bombay, India.

Cs-64. Patel, B., Mulay, C.D., and Ganguly, A.K., "Radioecology of Bombay Harbour--A Tidal Estuary", Estuar.Coast. Mar. Sci. 3, 13 (1975). Concentrations of ^{137}Cs are reported in a number of organisms collected from Bombay Harbour. Maximum concentrations of ^{137}Cs occurred in muscle tissues of the different fish species. CFs for ^{137}Cs in the flesh of various species of fish and shellfish from the harbor are reported.

4. Additional references to ^{137}Cs concentrations in fish from the vicinity of Bombay, India.

Cs-65. (See Ref. Pu-47). Concentrations of ^{137}Cs and ^{90}Sr are reported in fishes and invertebrates from the vicinity of Bombay Harbour between 1971-1974. ^{137}Cs levels in fish flesh ranged from 0.07 to 38 pCi/g wet.

Cs-66. (See Ref. Pu-48). Values of ^{137}Cs to $^{239+240}Pu$ are shown for tissues of fishes collected from Bombay harbour between 1970 and 1974. Concentrations of ^{137}Cs are in the range shown in Ref. Cs-65.

Table 3. Reported concentration factors for ^{137}Cs in fishes from regions of the world oceans and adjacent seas.

Common and/or scientific name	Year	Location	Total animal	Muscle	Bone	Liver	Ref.
Pacific (Source--global fallout, reactor and waste disposal sites)							
King salmon	1967	Alaskan waters		74		62	Cs-1
Chum salmon	1967	Alaskan waters		44 ± 4		31	Cs-1
Sockeye salmon	1967	Alaskan waters		47 ± 2	47	35	Cs-1
Silver salmon	1967	Alaskan waters		104 ± 59		25 ± 9	Cs-1
Albacore, Thunnus alalunga	1965-66	Northeast Pacific		103 ± 7			Cs-2
Bass, Epinephelus septemfasciatus	1963-70	Japanese coastal waters		11			Cs-4
Mackerel, Scomber japonicus	1963-70	Japanese coastal waters		25 ± 13			Cs-4
Porgy, Chrysophrys major	1963-70	Japanese coastal waters		28			Cs-4
Flathead, Platycephalus indicus	1963-70	Japanese coastal waters		30			Cs-4
Rockfish, Sebastes guntherii	1963-70	Japanese coastal waters		34 ± 11			Cs-4
Flounder, Limanda irrdorum	1963-70	Japanese coastal waters		36 ± 23			Cs-4
Jack, Seriola quinqueradiata	1963-70	Japanese coastal waters		40 ± 2			Cs-4
Jack, Konoshirus punctatus	1963-70	Japanese coastal waters		43			Cs-4
Scad, Trachurus japonicus	1963-70	Japanese coastal waters		46 ± 18			Cs-4
Sea bream, Mylio macrocephalus	1963-70	Japanese coastal waters		51 ± 15			Cs-4
Sardine, Sardinops melanosticta	1963-70	Japanese coastal waters		55			Cs-4
Mullet, Mugil cephalus	1963-70	Japanese coastal waters		58 ± 26			Cs-4
Halfbeak, Hemiramphus sajori	1963-70	Japanese coastal waters		59			Cs-4
Sea chub, Ditrema temmincki	1963-70	Japanese coastal waters		62 ± 5			Cs-4
Pacific cod, Gadus macrocephalus	1963-70	Japanese coastal waters		76			Cs-4
Sand smelt, Sillago sihama	1963-70	Japanese coastal waters		81			Cs-4
Dover sole, Microstomus pacificus	1972-73	Humboldt Bay, Calif.		37 ± 8			Cs-6
Young anchovy	1971-75	Tokai Mura, Japan	17 ± 1				Cs-7
Flounder, Flatfish	1971-75	Tokai Mura, Japan		26 ± 3			Cs-7
Rockfish, Sebastes sp.)	1977	Farallon Is., Calif.		86 ± 10			Cs-8
Mesopelagic fishes	1977-79	Japanese coastal waters		100			Cs-9
Pacific-Marshall Islands (Source--close-in and global fallout)							
Snapper, Lethrinus kallopterus	1975	Kwajalein Atoll		89 ± 11			Cs-22
Atlantic - Mediterranean-Indian (Source--global fallout, waste sites)							
Plaice, Pleuronectes platessa	unk	North Sea region		56			Cs-41
Sardine, Sardinella aurita	1967-69	Mediterranean Sea	21 ± 9[a]				Cs-43
Sardine, Sardina pilchardus	1967-69	Mediterranean Sea	26[a]				Cs-43
Mackerel, Scomber japonicus	1967-69	Mediterranean Sea	24[a]				Cs-43
Mullet, M. cephalus & M. capito	1967-69	Mediterranean Sea	25[a]				Cs-43
Rabbitfish, Siganus luridus	1967-69	Mediterranean Sea	10[a]				Cs-43
Porgy, Boops boops	1967-69	Mediterranean Sea	50[a]				Cs-43
Baraccuda, Sphyraena sp.	1967-69	Mediterranean Sea	44[a]				Cs-43
Goatfish, Upeneus moluccensis	1967-69	Mediterranean Sea	9[a]				Cs-43
Herring	<1963	Baltic Sea	200				Cs-40

Table 3. (Continued)

Common and/or scientific name	Year	Location	Total animal	Muscle	Bone	Liver	Ref.
Atlantic - Mediterranean-Indian (Source--global fallout, waste sites)							
Rat-tail, Macrurus rupestris	1979-80	NE Atlantic dump site		150			Cs-44
Yellow Scad, Selaroides leptoleptis	1980-81	Straits of Malacca	16[a]				Cs-45
Round Scad, Selap crumenophthalmus	1980-81	Straits of Malacca	342[a]				Cs-45
Coral Cod, Epinephelus pachycentron	1980-81	Straits of Malacca	372[a]				Cs-45
Stingray, Dasyatis zegei	1980-81	Straits of Malacca	272[a]				Cs-45
Atlantic (Source--reprocessing wastes and global fallout)							
Ray, Raja clavata	<1966	Windscale area			43 ± 26		Cs-53
Herring, Clupea harengus	<1966	Windscale area			50		Cs-53
Plaice, Pleuronectes platessa	<1966	Windscale area			36 ± 16		Cs-53
Plaice, Pleuronectes platessa	1965-66	Windscale area			45		Cs-54
Skate	1965-66	Windscale area			25		Cs-54
Plaice, Pleuronectes platessa	1969	Windscale area			27 ± 7		Cs-55
Mudskipper, Periopthalmus schlosseri	1968-69	Bombay Harbour, India		50 - 100			Cs-64
Bombay Duck, Harpodon nehereus	1968-69	Bombay Harbour, India		50 - 60			Cs-64
Silver pomfret, Pampus argenteus	1968-69	Bombay Harbour, India		45 - 50			Cs-64
Ribbonfish, Trichiurus savala	1968-69	Bombay Harbour, India		30 - 40			Cs-64
White sardine, Kowala coval	1968-69	Bombay Harbour, India		15 - 20			Cs-64
Golden anchovy, Coclia dussumieri	1968-69	Bombay Harbour, India		10 - 15			Cs-64
Burrowing goby, Trypauchen vagina	1968-69	Bombay Harbour, India		5 - 10			Cs-64

[a] Concentration reported as pCi/g dry wt. 4.2 was value used to convert dry to wet weight basis.

Cesium-137 Concentrations in Marine Invertebrates from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Sites)

1. References containing field-derived concentration factors for ^{137}Cs and stable Cs or both.

Cs-67. (See Ref. Cs-7). The range and average concentration in pCi/kg of ^{137}Cs are reported for shellfish flesh (range 1.2 to 4.7), cephalopod flesh (range 2.8 to 4.0) and whole Crustacea (range 2.4 to 5.7) collected between 1971 and 1975 from the coastal ocean offshore from Takai, Japan. CFs are computed.

Cs-68. (See Ref. Cs-9). Stable cesium concentrations were measured in coastal cephalopods from Japan. The CF for Cs, computed using a seawater concentration of 0.5 μg/ℓ, was 10.

Cs-69. Harrison, F.L., Wong, K.M., and Heft, R.E., Interactions of Radionuclides in Water, Particulates, and Oysters in the Discharge Canal of a Nuclear Power Plant, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-51974 (1976) 43 pp. The concentration factor determined for ^{137}Cs in oysters maintained in the discharge canal of the Humboldt Bay nuclear reactor was 50. The stable Cs CF was also determined; its value was 15. Results are expressed in pCi/kg wet wt.

Cs-70. (See Ref. Cs-10). Stable cesium was determined in the flesh of Pacific squid. An accumulation factor is computed using the value 0.3 μg/ℓ as the concentration of stable Cs in seawater.

2. Some additional references to levels of ^{137}Cs in invertebrates from the Pacific; no CFs reported.

Cs-71. (See Ref. Cs-17, Pu-6, Pu-52). Invertebrates, including squid, shrimp, crab, coral, brittle star, sea pen, snail, anemone, starfish, sponge, barnacle, worm and sea cucumber, were collected from the region of the Farallon Islands waste disposal site in 1977. ^{137}Cs was above detection limits only in a sample of eviscerated worms (0.13 ± 0.11 pCi/g dry wt.) and in a pooled viscera sample from 77 sea cucumbers (0.19 ± 0.06 pCi/g dry wt.).

Cs-72. (See Ref. Cs-6). ^{137}Cs concentrations are reported for the soft parts of clam, oyster and crab in monthly collections from Humboldt Bay, California, during 1972 and 1973. ^{137}Cs was above detection limits in some of the flesh samples of these invertebrates. The average concentration of ^{137}Cs during this period was 3 ± 1, 5 ± 43 and 4 ± 2 pCi/kg wet wt. in oysters, clams and crabs, respectively.

Cs-73. (See Ref. Pu-53). ^{137}Cs was measured in the soft parts of east and gulf coast mussels and oysters collected in 1976. The average concentration of ^{137}Cs in the tissue was 2.8 dpm/kg wet wt. Mussels from Bodega Head, California, collected between March 1976 and March 1977 averaged 3.7 ± 0.8 dpm/kg wet wt. and ranged in value from 2.5 to 4.6 dpm/kg wt.

B. Central Pacific Atolls and Locations Possibly Affected by Local Fallout from the Pacific Nuclear Test Sites

1. References containing field-derived concentration factors for ^{137}Cs.

No reported values.

2. Additional references to ^{137}Cs concentrations in invertebrates from Pacific atolls.

Cs-74. (See Ref. Cs-25). Concentrations of ^{137}Cs were above detection limits in a few samples of hepatopancreas, exoskeleton and muscle from spiny lobster collected at Bikini Atoll during May 1972. The maximum concentration of ^{137}Cs reported was 1.1 pCi/g dry in lobster hepatopancreas from Eneu Island.

Cs-75. (See Ref. Cs-27, Pu-16). ^{137}Cs was reported above detection limits only in the exoskeleton of lobster (0.03 ± 0.02 pCi/g dry) from Chistmas Island during August 1975.

Cs-76. (See Ref. Cs-33). ^{137}Cs was measured in samples of crab muscle and soft parts of clam collected from six islands sampled during the Dominic test series in 1962. ^{137}Cs values ranged from 0.73 pCi/g wet (Malden Island) to 0.75 pCi/g wet (Rarotonga).

Cs-77. (See Refs. Cs-36, Pu-10, Pu-56). Only two samples (a snail and a clam) contained ^{137}Cs at levels above detection limits from an extensive number of analyses of invertebrates collected between June 1956 and June 1957 from islands in the western Pacific. Concentrations ranged from 0.1 to 0.6 pCi/g dry.

Cs-78. (See Ref. Cs-37). ^{137}Cs was above detection limits in 89 of 470 samples of invertebrates collected from Bikini and Enewetak Atolls during 1964. Highest levels of ^{137}Cs recorded during this period were in the flesh of Coenobita (2000 pCi/g dry) from Namu Island, Bikini Atoll.

Cs-79. (See Refs. Cs-39, Pu-11). ^{137}Cs was measured in invertebrates collected during 1964 from Enewetak and Bikini. The average concentration of ^{137}Cs in soft parts and organs from invertebrates at Enewetak and Bikini during this period was 0.039 and 0.95 pCi/g dry, respectively. The invertebrates sampled are not indicated. No CFs are reported.

Cs-80. Robison, W.L., Noshkin, V.E., Phillips, W.A., and Eagle, R.J., The Northern Marshall Islands Radiological Survey: Radionuclide Concentrations in Fish and Clams and Estimated Doses via the Marine Pathway, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-52853 Pt. 3 (1981) 33 pp. Average ^{137}Cs concentrations are shown for muscle and mantle of giant clams collected during the 1978 survey of several northern Marshall atolls. Concentrations in muscle and mantle of the clams from the atolls ranged from less than 0.2 to 2.7 pCi/kg wet wt. Average ^{137}Cs levels in fish are also shown and were abstracted from Ref. Pu-17. No CFs are reported.

Cesium-137 Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{137}Cs and/or stable Cs.

Cs-81. (See Ref. Cs-42). Stable Cs was determined in the soft parts of several mollusks and crustaceans. CFs were computed by assuming a value of 0.34 μg/ℓ as the average concentration of cesium in seawater. The samples were collected along the southwest coast of the Cape of Good Hope.

Cs-82. (See Ref. Cs-43). Concentrations of ^{137}Cs are reported for marine invertebrates from the Mediterranean Sea. Crustacea samples included shrimp and crab. Concentrations of ^{137}Cs ranged from 0.017 to 0.050 pCi/g dry weight in the soft parts of these organisms. Mollusca contained 0.023 pCi/g dry in the soft part and 0.032 pCi/g dry in the shell. Concentrations of ^{137}Cs in Echinodermata ranged from 0.004 to 0.166 pCi/g dry. CF for ^{137}Cs in the invertebtrates are computed. All computed values are relative to the dry weight of the organism or tissue analyzed.

Cs-83. De Franclschi, L., Gentili, A., Gremigni, G., and Guidi, P., " ^{60}Co and ^{137}Cs in Mytilus edulis of Adriatic and Tyrrhenian Seas and an Estimate of Concentration Factors", Health Phys. 27, 400 (1974). Fallout levels of ^{137}Cs in the soft part of mussels ranged from <0.004 to 0.013 pCi/g wet. Many of the reported CFs were calculated from "less than" values. The average of all CFs above the detection limit in soft tissue was 9 ± 2.

2. Some additional references to concentrations accumulated by Atlantic invertebrates; no reported CFs.

Cs-84. (See Ref. Cs-44). The concentration of ^{137}Cs was determined in a variety of nektonic and benthic organisms including cuttle fish, crustacea, sea anemones, sea stars and sea cucumbers collected from the northeast Atlantic during 1979 and 1980. ^{137}Cs concentrations in benthic organisms ranged from 7.1 to 270 pCi/kg dry wt. and in nektonic species the concentration of ^{137}Cs was between 3.2 and 120 pCi/kg dry wt. No CFs for ^{137}Cs were computed.

Cs-85. (See Ref. Cs-53). Fallout concentrations of ^{137}Cs in clams, mussels, oysters and scallops collected between 1963 and 1965 from areas near Beaufort, NC, ranged from 2.22 in 1965 in oysters to 55.6 pCi/100 g wet wt. in 1963 in scallops. No CFs are computed.

Cs-86. (See Ref. Pu-61). Fallout concentration ratios of ^{137}Cs to $^{239+240}Pu$ are tabulated for a number of marine invertebrates collected from the vicinity of Cape Cod, MA, during 1970. No CFs are computed.

B. Coastal and Ocean Studies (Source Term--Reprocessing Facilities Discharges)

1. References containing field-derived concentration factors for ^{137}Cs and/or stable Cs in invertebrates from both the immediate vicinity and at distances from Windscale releases.

Cs-87. (See Ref. Cs-56). Concentration factors for stable Cs are compared with values for radiocesium in mollusks and crustaceans collected from the vicinity of Windscale. In the soft parts of mollusks, the CF for stable Cs ranged from 22 to 28 and for radiocesium the value ranged from 9 to 72. In crustacean tissue, the CF for stable cesium was between 22 and 26, and for radiocesium the value of the CF was 29 to 30.

Cs-88. (See Ref. Cs-57). Concentration factors of ^{137}Cs are shown in accompanying tables for mollusks and crustaceans from the vicinity of the Windscale discharge during 1965-1966. ^{137}Cs levels in oyster flesh from the Blackwater Estuary ranged from 0.17 pCi/g wet at the power station outfall to 0.041 pCi/g wet at 1/3 mile from the outfall. The year of collection is not provided.

2. Additional references to ^{137}Cs concentrations in invertebrates from the immediate vicinity and at distances from Windscale discharges.

Cs-89. (See Ref. Cs-59, Pu-45, Pu-81). Concentrations of ^{137}Cs are reported in a variety of shellfish collected between 1977 and 1980 from the Windscale shoreline area, from other vicinities in the Irish Sea and from regions adjacent to other nuclear facilities in England. Results are provided for crabs, winkles, mussels, lobsters, limpets, shrimps, cockles, scallops, prawns, squid, queens and nephops from the different regions sampled. No CFs are computed.

Cs-90. (See Ref. Cs-62). This series of reports include monitoring data for ^{137}Cs and other radionuclides in different invertebrates collected from regions of the British Isles and other nearby vicinities. No CFs are provided.

Cs-91. (See Ref. Pu-79). ^{137}Cs concentrations are reported in the clam muscle (13 pCi/g wet) and digestive gland (20 pCi/g wet) of Cancer pagurus and in the total soft part of Mytilus edulis (7.5 pCi/g wet) collected from the Windscale pipeline during 1977-1978. No CFs for ^{137}Cs are computed.

Cs-92. Woodhead, D.S., "Levels of Radioactivity in the Marine Environment and the Dose Commitment to Marine Organisms," Radioactive Contamination of the Marine Environment (Proc. Symp., Seattle WA 1972) IAEA, Vienna (1973), 499. Tables of data extracted from the literature show fallout levels of different radionuclides including ^{137}Cs in marine organisms. Reference is also made to the levels of ^{137}Cs detected in oysters collected in the Blackwater Estuary during 1968.

3. References containing field-derived concentration factors for ^{137}Cs in invertebrates from the vicinity of the Bhabha Atomic Research Center, Bombay, India.

Cs-93. (See Ref. Cs-64). The range in values for the concentration factor of ^{137}Cs in the flesh of different species of shell fish from Bombay Harbour is provided. In bivalves, the CF for ^{137}Cs was lowest in oyster (20-50). The value ranged from 500 to 10^4 in blood clam. For crustaceans, maximum values for the CF of ^{137}Cs were found in the flesh of rock crab (100 to 10^5).

4. Additional references to ^{137}Cs concentrations in invertebrates from the vicinity of Bombay, India.

Cs-94. (See Ref. Cs-65). Concentrations of ^{137}Cs are reported in crabs and prawns collected between 1970 and 1974 from vicinities within Bombay Harbour. ^{137}Cs levels in the flesh of crabs ranged from 3 to 20 pCi/g wet weight during this period, and concentrations in whole prawns ranged from 0.11 to 8 pCi/g wet. No CFs are computed.

Cs-95. (See Ref. Cs-66, Pu-48). Ratios of ^{137}Cs to $^{239+240}Pu$ are tabulated for the flesh and bone of Scylla serrata collected between 1970 and 1974 from vicinities within Bombay Harbour. No CFs are provided.

Cs-96. Patel, B., Valanju, P.G., Mulay, C.D., Balani, M.C., and Patel, S., "Radioecology of Certain Molluscs in Indian Coastal Water," Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle, 1972) IAEA, Vienna (1973), 307. The concentrations of ^{137}Cs in various tissues of Aplysia benedicti (sea hare) collected in January 1972 from Tarapur waters are tabulated. Results are expressed as pCi/g in freeze-dried tissue. Highest concentrations of ^{137}Cs were associated with the stomach and intestine (66.5 pCi/g). ^{137}Cs was not detected in the shell. CFs are not provided.

Cs-97. Bhat, I.S., Patel, S., Patel, B., and Kamatk, P.R., "Cycling of Radionuclides and Impact of Operational Releases in the Near-Shore Ecosystem off the West Coast of India", Impacts of Radionuclide Releases into the Marine Environment (Proc. Symp. Vienna 1980) IAEA, Vienna (1981), 431. Marine organisms used as seafood (prawns, crabs, oysters, clams, lobsters, onchedium and nerita species) were collected from the Tarapur, India, coastal environment between 1975 and 1979 and analyzed for ^{137}Cs, ^{90}Sr, and ^{60}Co. Figures showing the annual maximum and the average radionuclide content in these coastal seafoods are provided. The authors state that ^{137}Cs and ^{90}Sr at fallout levels were detected in coastal organisms beyond 10 km of the TAPS site. No CFs are reported.

Table 4. Reported concentration factors for ^{137}Cs in invertebrates from regions of the world oceans.

Common and/or scientific name	Year	Location	Whole animal	Soft tissue	Shell	Flesh	Ref.
MOLLUSCA							
Cephalopoda							
Octopus-Squid	1971-75	Tokai, Japan				11.5	Cs-67
Squid, Sepia officinalis	1968-69	Mediterranean		47[a]	65[a]		Cs-82
Gastropoda							
Winkle	1965-66	Windscale area		100			Cs-88
Limpet	1965-66	Windscale area		70			Cs-88
Winkle, Littorina littorea	<1966	Windscale area		18 - 72			Cs-87
Pelecypoda							
Mussel	1965-66	Windscale area		15			Cs-88
Oyster	1973	Humboldt Bay, Calif.		50			Cs-69
Shellfish	1971-75	Tokai, Japan				8.2	Cs-67
Mussel, Mytilus edulis	<1966	Windscale area		9			Cs-87
Mytilus edulis	1962-71	Adriatic		9			Cs-83
Oyster, Ostrea edulis	<1966	Windscale area		13			Cs-87
Blood clam, Anadara granosa	1968-69	Bombay Harbor area		500 - 10^6			Cs-93
Oyster, Crassostera cucullata	1968-69	Bombay Harbor area		20 - 50			Cs-93
Windowpane oyster, Placenta placenta	1968-69	Bombay Harbor area		400 - 700			Cs-93
Clam, Paphia malabarica	1968-69	Bombay Harbor area		500 - 800			Cs-93
Clam, Merebrix meretrix	1968-69	Bombay Harbor area		200 - 400			Cs-93
ARTHROPODA							
Crustacea							
Lobster	1965-66	Windscale area				25	Cs-88
Whole Shrimp	1965-66	Windscale area	100				Cs-88
Shrimp, Parapenaeus longirostris	1968-69	Mediterranean	102[a]				Cs-82
Crab, Charybolis longicollis	1968-69	Mediterranean	57[a]				Cs-82
Shrimp, Penaeus japonicus	1968-69	Mediterranean	46[a]				Cs-82
Shrimp, Metapenaeus monoceros	1968-69	Mediterranean	57[a]				Cs-82
Shrimp	1971-75	Tokai, Japan	20 ± 10				Cs-67
Lobster, Homarus vulgaris	<1966	Windscale area				29	Cs-87
Crab, Cancer pagurus	<1966	Windscale area				30	Cs-87
Prawn, Penaeus sp.	1968-69	Bombay Harbor		50 - 100			Cs-93
Rock Crab, Seylla serrata	1968-69	Bombay Harbor		10^2 - 10^5			Cs-93
Barnacles, Balanus amphitrite	1968-69	Bombay Harbor		50 - 100			Cs-93
ECHINODERMATA							
Asteroidea							
Astropecten aranciacus	1968-69	Mediterranean	8[a]				Cs-82
Echinoidea							
Brissopris lyrifera	1968-69	Mediterranean	300 ± 40[a]				Cs-82

[a] dry wt. concentration factor

Strontium-90 Concentrations in Marine Fish from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Sites)

1. References containing field-derived concentration factors for ^{90}Sr and/or stable strontium.

Sr-1. Ueda, T., Suzuki, Y., and Nakamura, R., "Accumulation of Sr in Marine Organisms--I. Strontium and Calcium Contents, CF and OR Values in Marine Organisms," Bull. Japan. Soc. Sci. Fish. 39, 1253 (1973). The amounts of Sr and Ca in different marine organisms were determined by atomic absorption spectroscopy (AAS) and the concentration factor (CF: Sr organism/Sr seawater) and observed ratio (OR: (Sr/Ca) organism/(Sr/Ca) seawater) were calculated. Stable strontium in fish bone ranged from 78 to 293 mg/kg raw weight. The CF of stable strontium in fish bone ranged from 10 to 37 and averaged 26 $\pm$ 7. The concentration factor for stable Sr in fish flesh ranged from 0.2 to 0.4 and averaged 0.3. The authors state that there was no difference in the CF between warm current species and cold current ones or between migratory and nonmigratory species. The reported CF values for the stable element are not included in the tables in this report.

Sr-2. Ueda, T., Suzuki, Y., and Nakamura, R., "Accumulation of Sr in Marine Organisms--II. The Level of ^{90}Sr in Marine Organisms from the Coastal Sea of Japan," Bull. Japan. Soc. Sci. Fish. 41, 691 (1975). During the period 1963-1971, fallout ^{90}Sr was determined in different fish (whole body and bone) and mollusk shells collected from the coastal waters of Japan. All results are expressed in terms of a strontium unit: SU = ^{90}Sr pCi per gram of calcium. These values ranged from 0.1 to 0.7 in the bone of fish and from 0.1 to 0.3 in the whole body samples analyzed. In Mollusca shells the range in the SU value was between 0.1 to 0.4. CFs are compiled for bone and whole body of fish and for mollusk shells. For fish bone the CF ranged from 35-62, and for whole fish the range was between 22 and 24. The values are stated to be in agreement with stable strontium concentration factors.

Sr-3. (See Refs. Cs-7, Cs-67, Pu-3, Pu-50). The average and range of ^{90}Sr concentrations are reported for whole Shirasu (young of anchovy) and the flesh of adult fish obtained between 1971 and 1975 from the coastal ocean offshore Tokai, Japan. The average concentration in Shirasu was 0.93 pCi/kg wet wt. and ranged between 0.17 and 2.70 pCi/kg. In adult fish the mean concentration was 0.86 and ranged from 0.26 to 1.86 pCi/kg. The ^{90}Sr CF for Shirasu was 3.4 and for adult fish the computed value was 3.2.

2. Some additional references to fallout levels of ^{90}Sr in Pacific fish; no reported CFs.

Sr-4. (See Ref. Cs-9). The levels of fallout ^{90}Sr were measured in the bone of several species of mesopelagic and coastal fishes caught in the western Pacific during 1979. The average concentration of ^{90}Sr in the bone of mesopelagic fish (1.4 ± 0.6 pCi/kg wet) is, according to the authors, slightly lower than the mean concentration (1.7 ± 1.6 pCi/kg) in bone of coastal fish.

Sr-5. (See Ref. Cs-18). This report contains ^{90}Sr concentrations measured in fish tissue samples collected from regions of the Pacific contaminated with local fallout from the Pacific Proving Grounds, and also in the bone of fish contaminated by global fallout. The liver of a big-eyed tuna, caught 80 miles from Bikini Atoll during October 1956, contained 20 pCi/g of ^{90}Sr. Soon after the 1962 test series, 19 tuna collected from the mid Pacific were found to contain from 0.3 to 1.3×10^{-3} pCi/g of ^{90}Sr. Marine species from the sea of Japan collected between 1963 and 1966 contained from 0.5-0.7 pCi of ^{90}Sr/g of stable Ca in the bone. No CFs are reported.

Sr-6. Kawabata, T., "Radio-nuclides in Tissues and Organs of the Pacific Tuna," Radio-active Contamination of Marine Products in Japan, U.S. Gov. Doc. Np-8862 (1960), 3. ^{90}Sr was measured in fish bones (vertebrae of yellowfin and big-eye tuna) collected at the Tokyo fish market in 1958. Concentration of ^{90}Sr expressed as pCi/g Ca ranged from 0.09 to 0.26. No CFs are computed.

Sr-7. Hiyama, Y., Shimizu, M. Matsubara, J., Asari, T., Ariki, T., and Ichikawa, R., "^{90}Sr in Marine Organisms in Japan," Radio-active Contamination of Marine Products in Japan, U.S. Gov. Doc. Np-8862 (1960), 9. ^{90}Sr was determined in bones of different fish collected from the fish market in Tokyo between 1956

and 1958. During this period, ^{90}Sr levels in bones of surface-feeding fish decreased while levels in bottom dwellers increased. Concentrations are expressed as both ^{90}Sr pCi/g of Ca, with a range from 0.07 to 0.56, and ^{90}Sr pCi/7 mg of Sr with a range of 0.22 to 8.4. No CFs are computed.

Sr-8. Weichold, B., Ed., Bioenvironmental Features of the Ogatoruk Creek Area, Cape Thomspon, Alaska, A Second Summary, Committee on Environmental Studies for Project Chariot, USAEC Div. of Tech. Info. Rept. TID-17226 (1962) 183 pp. Samples of marine life were collected for ^{90}Sr analysis during 1961 in the Chukchi Sea near the Chariot site, including seal, whale, walrus, salmon, whitefish, and char. In the muscle of fish the ^{90}Sr concentrations ranged from 3.5 to 7.0 pCi/kg while in the walrus, seal, and whale the range was only between 0.22 and 0.91 pCi/kg. In whitefish and char, ^{90}Sr levels in liver exceeded those in bone while in the salmon, bone concentration was higher. Another table in the report provides concentrations expressed as pCi/g of wet tissue. The concentration in fish muscle ranged from 0.0028 to 0.0068; in bone from 0.0082 to 0.14; and in liver from 0.027 to 0.20. No CFs are computed.

Sr-9. (See Refs. Cs-17, Cs-71, Pu-6, Pu-52). Selected organisms collected near the Farallon Islands waste disposal site were analyzed for ^{90}Sr. Concentrations in fish muscle ranged from non-detectable levels to 0.096 ± 0.025 pCi/g dry in sablefish muscle. No CFs are reported.

B. Central Pacific Atolls and Locations Possibly Affected by Local Fallout from the Pacific Nuclear Test Series

1. References containing field-derived concentration factors for ^{90}Sr.

No reported values.

2. Additional references to ^{90}Sr concentrations in fish from Pacific Atolls.

Sr-10. (See Refs. Cs-29, Pu-18). ^{90}Sr concentrations in a variety of dissected parts from different species of fish collected during a 1978 survey of Rongelap, Utirik, Taka, Bikar, Rongerik, Alinginae, Likiep, Jemo, Ailuk, Mejit, Wotho, and Ujelang are shown. All concentration data are expressed as pCi/kg wet wt. and

dry/wet weight ratios are provided for conversion purposes. The average ^{90}Sr concentration in the flesh of fish from all the atolls is: surgeonfish, 0.8 ± 0.6 pCi/kg wet; mullet, 0.5 ± 0.3; goatfish, 0.5 ± 0.6; parrot fish, 0.5 ± 0.4; other reef fish, 0.3 ± 0.2; all pelagic lagoon fish, 0.3 ± 0.2 pCi/kg. No CFs were computed.

Sr-11. (See Ref. Cs-23). ^{90}Sr was determined in a variety of eviscerated whole reef fish collected from the islands of Nam and Bikini, Bikini Atoll, during 1969. The authors note that the smaller, and presumably younger, reef fish of a species contain less ^{90}Sr than the larger fish of the same species. Presumably, the ^{90}Sr is being accumulated throughout the life of the fish and a steady state has not been reached. The average value in pCi/g wet for ^{90}Sr in reef fish was 0.08. No CFs are reported.

Sr-12. (See Refs. Cs-25, Cs-74). ^{90}Sr levels are reported for five samples of eviscerated whole fish collected at Bikini during May 1972. The authors state that the ^{90}Sr levels in fish remained similar to levels present in 1969.

Sr-13. (See Refs. Cs-27, Cs-75, Pu-16). ^{90}Sr concentrations are reported in a variety of fish collected from Rongelap, Utirik, and Rongerik Atolls in 1974 and from Bikini Atoll in 1974 and 1975. Most fish tissues contained less than 1 pCi/g dry weight. The highest value for ^{90}Sr (2.6 pCi/g) was measured in the viscera of mullet from Nam Island, Bikini Atoll. No CFs are provided.

Sr-14. (See Refs. Cs-28, Pu-17). ^{90}Sr was reported above detection limits only in an eviscerated convict surgeonfish (0.05 ± 0.02 pCi/g dry) from Ponape collected in 1975. The ^{90}Sr content in 14 other fish tissue samples analyzed was below detection limits.

Sr-15. (See Refs. Cs-32, Pu-12, Pu-57). This is a summary and discussion of the results from a radiological survey of Enewetak Atoll conducted in 1972-1973. Concentrations of ^{90}Sr are reported in tissue and organs from a variety of reef and lagoon pelagic species. Most values in fish from the southeast quadrant of the lagoon were less than 0.1 pCi/g dry. Among the pelagic lagoon species, ^{90}Sr was highest in the muscle of the barracuda (0.05 ± 0.01 pCi/g dry) collected near Mike Crater.

Sr-16. (See Ref. Cs-33, Cs-76). Concentrations of ^{90}Sr are reported in samples of three fish collected at Christmas and Malden Islands during 1962. The highest concentration was determined in an entire goby (171 $\pm$ 142 pCi/g wet) from Christmas Island. No CFs are computed.

Sr-17. (See Refs. Cs-36, Cs-77, Pu-10, Pu-56). Only three positive determinations of ^{90}Sr in the bones of surgeonfish were recorded from an extensive number of analyses on fish collected between June 1956 and June 1957 from islands in the western Pacific. The average concentration in the bone was approximately 0.6×10^{-6} μCi/g.

Sr-18. (See Ref. Cs-38). ^{90}Sr was determined in the muscle of wahoo and yellowfin tuna collected in the vicinity of Christmas Island during 1962. The average concentration in the muscle was 0.038 pCi/g wet. Tuna liver contained 0.053 pCi/g wet. No CFs are computed.

Sr-19. (See Refs. Cs-39, Cs-79, Pu-11). Concentrations of ^{90}Sr in the muscle of fish collected during 1964 from Enewetak Atoll averaged 0.77 pCi/g dry. No CFs are computed.

Strontium-90 Concentrations in Marine Fish from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. Reference containing field-derived concentration factors for ^{90}Sr and/or stable strontium.

Sr-20. Cigna, A.A., Ferraris, M.M., Giorcelli, F.G., and Papucci, C.L., "Some Measurements of Fallout Contamination in the Mediterranean Sea," The Proceedings of a Symp. on Nuclear Detonations and Marine Radioactivity, Small, S.H., Ed., Norwegian Defense Research Establishment, Kjeller (1963), 95. Samples of Mytilus galloprovincialis collected in March and April 1962 contained 15 pCi/kg wet weight of ^{90}Sr in the soft parts. The concentration of ^{90}Sr measured in the whole body of Sardina pilcardus was 8 pCi/kg wet and the CF was reported as 9.7 $\pm$ 0.6.

Sr-21. Mauchline, J., and Templeton, W.L., "Strontium, Calcium, and Barium in Marine Organisms from the Irish Sea", J. Cons. Perm. In't. Explor. Mer. 30, 161 (1966). Stable strontium was determined in 45 species of invertebrates and 6 species of fish from the Irish Sea. Concentration factors for Sr of less than 1.0 were found in the muscle of fish while in bone the values ranged from 30 to 50.

Sr-22. (See Refs. Cs-44, Cs-84). ^{90}Sr was determined in different nektonic and benthic organisms caught in the northeast Atlantic during 1979-1980. Concentrations (pCi/kg dry wt.) in nektonic organisms ranged from 1.2 to 40; in benthic organisms the range was from 0.8 to 310 pCi/kg. Highest levels of ^{90}Sr were found in benthic organisms from the area of the original NEA dumpsite at 5200 m. The content of ^{90}Sr in sea anemones from this site was at least one order of magnitude higher than the level detected in 1966 from this area or in samples from the 1979/1980 study area B (present dumping site) or area C (control site). No CFs are reported for the invertebrates but the authors compute a value of 30 for the CF of ^{90}Sr in the flesh of a rat-tail fish from the region.

2. Some additional references to fallout concentrations accumulated by Atlantic fish; no reported CFs.

Sr-23. (See Ref. Cs-47). Measured values for ^{90}Sr expressed as pCi/g Ca are shown for fish collected from the N. Atlantic, Norwegian Sea, Barents Sea, North Sea, and Baltic Sea during 1961 and 1962. The concentrations of fallout ^{90}Sr in fish from the North and Baltic Sea were larger than levels in fish from the N. Atlantic. CFs are not computed.

Sr-24. (See Ref. Cs-48). From an analysis of cod caught in the Baltic Sea the author provides the fallout ^{90}Sr distribution as 67% in bone, 10% in stomach and intestines, 9% in skin, 7% in gills, 1% in gonad and 6% in remaining tissue.

Sr-25. Berge, G., "Radioactivity in Fish from the Barents Sea," The Proc. of a Seminar on Nuclear Detonations and Marine Radioactivity, Small, S.H., Ed., Norwegian Defense Research Establishment, Kjeller (1963), 127. Radiochemical analysis revealed very low levels of ^{90}Sr in fish from the Barents Sea collected during the summer of 1962, during the period of maximum radioactive contamination.

The following concentrations of ^{90}Sr in strontium units were determined: cod, 0.3 ± 0.3 SU; haddock, 1.2 ± 0.6 SU; and spotted catfish, 0.3 ± 0.3 SU. No CFs were computed.

B. Coastal and Ocean Studies (Source Term--Reprocessing Facilities Discharges)

1. References containing field-derived concentration factors for ^{90}Sr and/or stable Sr in fish from both the immediate vicinity and at distances from the Windscale releases.

Sr-26. (See Refs. Cs-56, Cs-87). Concentration factors for stable Sr are compared with values for ^{90}Sr from environmental measurements made near Windscale. Values are provided for mollusk, crustaceans, and some fish.

Sr-27. (See Refs. Cs-57; Cs-88). Concentrations of ^{90}Sr in the flesh of plaice (0.006 pCi/g wet) and skate (0.006 pCi/g wet) collected in the vicinity of Windscale during 1965 are shown. CFs for ^{90}Sr are computed for mollusks, plaice, and skate from Windscale data collected during 1965-1966.

Sr-28. (See Ref. Cs-60). ^{90}Sr concentrations in tissues of rays from the area at the end of the Windscale pipeline are shown for samples collected during July and August 1961. Highest ^{90}Sr levels were associated with the liver, followed by (in order of decreasing values) skin, cartilage, stomach contents, stomach, and flesh. Values are reported as pCi/g wet weight. CFs for ^{90}Sr in the flesh, cartilage, and stomach were 0.5, 16.4 and 11.6, respectively.

2. Additional references to ^{90}Sr concentrations in fish from both the immediate vicinity and at distances from Windscale releases.

Sr-29. (See Ref. Cs-63). Figures are provided showing the change in ^{90}Sr concentration in muscle of Pleuronectes platessa as a function of distance from the Windscale discharge during 1964. No CFs are computed.

Sr-30. Howells, H., "Discharges of Low-Activity, Radioactive Effluent from the Windscale Works into the Irish Sea," Disposal of Radioactive Wastes into Sea, Oceans and Surface Waters (Proc. Symp. Vienna 1966), IAEA, Vienna (1966), 769. The author provides tables of monitoring results, showing the average

concentration of ^{90}Sr in fish collected at Windscale between 1959 and 1965. Concentrations ranged from 0.02 to 0.05 pCi/g during this period. No CFs are provided.

3. References containing field-derived concentration factors for ^{90}Sr in fish from the vinicity of the Bhabha Atomic Research Center, Bombay, India.

No reported values.

4. Additional references to ^{90}Sr concentrations in fish from the vicinity of Bombay, India.

Sr-31. (See Refs. Cs-65, Cs-94, Pu-47). Some ^{90}Sr concentrations (pCi/g wet) are tabulated for crab, mackerel, catfish, arca, sardine, and prawn from vicinities within Bombay Harbor, India. Highest concentrations were found in the bones of fish and shells of invertebrates. No CFs are computed.

Table 5. Reported concentration factors for ^{90}Sr in fishes from regions of the world oceans and adjacent seas.

Common and/or scientific name	Year	Location	Total animal	Muscle	Cartilage	Bone	Ref.
Pacific (Source--global fallout)							
Mackerel	1965-66	Coastal Sea of Japan				62	Sr-2
Japanese horse mackerel	1963-66	Coastal Sea of Japan				39	Sr-2
Sand flounder	1963-66	Coastal Sea of Japan				33	Sr-2
Black porgy	1965-66	Coastal Sea of Japan				51	Sr-2
Japanese horse mackerel	1970	Coastal Sea of Japan	22				Sr-2
Sand flounder	1967-69	Coastal Sea of Japan	20				Sr-2
Shirasu (young anchovy)	1971-75	Tokai, Japan	3.0				Sr-3
Flounder	1971-75	Tokai, Japan		3.2			Sr-3
Atlantic - Mediterranean (Source--global fallout, waste sites)							
Sardina pilcardus	1962	Mediterranean	9.8				Sr-20
Rat-tail fish	1979	NE Atlantic dump site		30			Sr-22
Atlantic (Source--reprocessing wastes, global fallout)							
Raja clavata	1961	Windscale area		0.5	16.0		Sr-28
Raja batis	<1966	Windscale area		0.3			Sr-26
Raja clavata	<1966	Windscale area		0.6	12		Sr-26
Pleuronectes platessa	<1966	Windscale area		0.3			Sr-26
Plaice	1965-66	Windscale area		0.3			Sr-27
Skate	1965-66	Windscale area		0.3			Sr-27

Strontium-90 Concentrations in Marine Invertebrates from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{90}Sr.

Sr-32. (See Ref. Sr-1). The amounts of stable Sr and Ca in exoskeleton of crustacea, in mollusca shells and in echinodermata and coelenterata were determined by AAS. Concentration factors (Sr organism/Sr seawater) and observed ratios (OR: (Sr/Ca) organism/ (Sr/Ca) seawater) were calculated. Stable Sr in exoskeleton of Crustacea ranged from 140 to 1950 mg/kg raw weight and the average CF was 100 ± 50. In Mollusca shells, stable Sr ranged from 17 to 1600 mg/kg raw weight. The reported values for the CFs of stable strontium are not given in the tables in this report.

Sr-33. (See Ref. Sr-2). During the period 1965-1970, fallout ^{90}Sr was determined in mollusk shells collected from the coastal waters of Japan. All results are expressed in SU units (^{90}Sr pCi $(gCa)^{-1}$). The range in the SU values was from 0.1 to 0.4. CFs are estimated to range from 40 to 205 in the molluscan shells.

Sr-34. (See Refs. Sr-3, Cs-7, Cs-67, Pu-3, Pu-50). The concentration range and means for ^{90}Sr are reported for shellfish, cephalopoda and crustacea collected between 1971 and 1975 from the coastal ocean offshore from Tokai, Japan. In shellfish the range in ^{90}Sr levels in flesh was between 0.57 and 3.4 pCi/kg wet and averaged 1.4 pCi/kg; in cephalopoda flesh the average concentration was 0.44 pCi/kg and ranged from 0.17 to 1.0 pCi/kg; in whole crustacea the mean ^{90}Sr level was 7.6 pCi/kg and ranged from 2.9 to 12.8 pCi/kg. CFs for ^{90}Sr are shown in the tables.

2. Some additional references to ^{90}Sr in Pacific invertebrates; no reported CFs.

Sr-35. (See Refs. Sr-9, Cs-17, Cs-71, Pu-6, Pu-52). Selected benthic organisms collected near the Farallon Islands waste disposal site were analyzed for ^{90}Sr. Highest concentrations were found in brittle star (0.103 pCi/g dry) and lithodid crab exoskeleton (0.083 ± 0.031 pCi/g dry).

Sr-36. Nakai, Z., Fukai, R., Harumi, T., Hattori, S., Okobo, K., and Kidachi, T., "Radioactivity of Marine Organisms and Sediments in the Tokyo Bay and its Southern Neighbourhood", Radio-active Contamination of Marine Products in Japan, United States Government Document Np-8862 (1960) 18. A variety of nektonic and benthic invertebrates were collected for radionuclide analysis from regions of Tokyo Bay, Sagami Bay, and a region south of Boso Peninsula between 1957 and 1959. In nektonic organisms, the concentrations of ^{90}Sr, expressed as pCi/g ash, ranged from 0.012 to 0.14 while in benthic organisms the concentration ranged from 0.009 to 0.11. No CF are computed.

B. Central Pacific Atolls and Locations Possibly Affected by Local Fallout from the Pacific Nuclear Test Series

1. References containing field-derived concentration factors for ^{90}Sr.

No reported values.

2. Additional references to ^{90}Sr concentrations in invertebrates from Pacific Atolls.

Sr-37. (See Refs. Sr-19, Cs-39, Cs-79, Pu-11). Concentrations of ^{90}Sr in the muscle of sea invertebrates (unidentified) collected from Bikini Atoll in 1964 averaged 0.18 pCi/g dry weight. No CFs are reported.

Sr-38. (See Refs. Sr-17, Cs-36, Cs-77, Pu-10, Pu-56). Several samples of clam collected from regions of the Pacific in 1957 contained detectable levels of ^{90}Sr ranging from 0.06 to 4.4 pCi/g.

Sr-39. (See Refs. Cs-37, Cs-78). ^{90}Sr was determined in marine invertebrates collected during 1964 from islands of Bikini Atoll. In Tridacna clam muscle the concentration was 0.18 ± 0.12 pCi/g dry. In muscle of hermit crab the ^{90}Sr level ranged from 200 to 630 pCi/g. No CFs are reported.

Sr-40. (See Refs. Sr-13, Cs-27, Cs-75, Pu-16). ^{90}Sr measurements were attempted for various tissues from Tridacna clams from Utirik, Rongelap and Bikini in 1974 and 1975. ^{90}Sr was above detection limits only in the kidney of a clam from Bikini (0.10 ± 0.06 pCi/g dry) and in the mantle tissue of a sample from Utirik (0.91 ± 0.12 pCi/g dry).

Sr-41. (See Ref. Cs-80). ^{90}Sr concentrations are shown for muscle and mantle of giant clams collected during a 1978 survey of several Northern Marshall Atolls. Concentrations ranged from less than 1 to 10 pCi/kg wet wt.

Sr-42. (See Refs. Sr-15, Cs-32, Pu-12, Pu-57). This is a summary and discussion of the results from a radiological survey of Enewetak Atoll conducted in 1972 and 1973. ^{90}Sr was determined in tissues of Tridacna clams, spiny lobster, pencil urchins and top snails collected from different islands of the atolls. Concentrations in clams ranged from non-detectable levels to 1.9 pCi/g dry in the viscera. Lobster muscle contained less than 0.02 pCi/g dry.

Strontium-90 Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea

A. Coastal and Ocean Studies (Source--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{90}Sr.

No reported values.

2. Some additional references to concentrations accumulated by Atlantic invertebrates.

Sr-43. (See Refs. Cs-86, Pu-61). Fallout concentration ratios of ^{90}Sr to $^{239+240}Pu$ are tabulated for a number of marine invertebrates collected from the vicinity of Cape Cod, MA, during 1970. The range in the concentration ratio was from 0.8 to 12.6 in the invertebrates collected. No CFs are reported.

Sr-44. (See Refs. Sr-22, Cs-44, Cs-84). ^{90}Sr was determined in different nektonic and benthic organisms caught in the northeast Atlantic during 1979-1980. Concentrations (pCi/kg dry wt.) in nektonic organisms ranged from 1.2 to 40; in benthic organisms the range was from 0.8 to 310 pCi/kg. Highest levels of ^{90}Sr were found in benthic organisms from the area of the original NEA dumpsite at 5200 m. The content of ^{90}Sr in sea anemones from this site was at least one order of magnitude higher than the level detected in 1966 from this area or in samples from the 1979-1980 study area B (present dumping site) or area C (control site). No CFs are reported for the invertebrates.

Sr-45. (See Ref. Sr-20). Samples of Mytilus galloprovincialis collected in March and April 1962 from the Mediterranean contained 15 pCi/kg wet weight of ^{90}Sr in the soft parts.

Sr-46. Templeton, W.L., "Transfer of Radionuclides from the Environment through Aquatic Food Products to Man", Agricultural and Public Health Aspects of Radioactive Contamination in Normal and Emergency Situations (Proc. Sem. Dec. 11-15, 1961, Scheveningin, The Netherlands) FAO, Rome, 43. A comparison is provided between estimated ^{90}Sr activity in lobster derived from stable element estimations and the actual ^{90}Sr levels due to fallout from weapons tests. The estimated accumulation factor was 1 for flesh; 180 for shell and 33 for the remainder of the organism. The estimated levels of ^{90}Sr agreed well with the measured concentrations.

B. Coastal and Ocean Studies (Source Term--Reprocessing Facilities Discharges)

1. References containing field-derived concentration factors for ^{90}Sr from the immediate vicinity and at distances from the Windscale releases.

Sr-47. (See Refs. Sr-27, Cs-57, Cs-88). Concentration factors for ^{90}Sr determined in mussels, winkles and limpets collected from the vicinity of Windscale during 1965-1966. These values are shown in the companion tables.

Sr-48. (See Refs. Sr-26, Cs-56, Cs-87). Concentration factors for stable Sr are compared with radiostrontium in mollusks collected from the vicinity of Windscale. In the soft parts of mytilus edulis the ^{90}Sr CF is 8 while the value for stable Sr is 10. Values are shown in the companion table.

2. Additional references to ^{90}Sr concentrations from both the immediate vicinity and at distances from Windscale releases.

Sr-49. (See Ref. Sr-29; Cs-63). Levels of ^{90}Sr in the soft tissue and shell of mytillus edulis collected from several locations near the Windscale pipeline during 1964 ranged from 0.07 to 1.1 and 2.3 to 6.6 pCi/g wet, respectively. No CFs were computed.

3. References containing field-derived concentration factors for ^{90}Sr in invertebrates from the vicinity of the Bhabha Atomic Research Center, Bombay, India.

No reported values.

4. Additional references to ^{90}Sr concentrations.

Sr-50. (See Refs. Sr-31, Cs-65, Cs-94, Pu-47). Concentrations of ^{90}Sr are reported in crabs and prawns collected between 1970 and 1974 from vicinities within Bombay Harbour. The ^{90}Sr level in the flesh of crabs collected during 1970 was 9.6 pCi/g wet and the concentration in prawn flesh collected during 1973 was 0.0067 pCi/g wet. No CFs are computed.

Sr-51. (See Ref. Cs-97). Figures show the annual maximum and average ^{90}Sr content in coastal organisms collected between 1975-1979 from the environment near Tarapur. ^{90}Sr was detected at fallout levels in these organisms beyond 10 km of the TAPS site, according to the authors. The average concentration during this period ranged from 0.2 to 0.1 Bq/kg soft tissue.

Table 6. Reported concentration factors for ^{90}Sr in invertebrates from regions of the world oceans and adjacent seas.

Common and/or scientific name	Year	Location	Whole animal	Soft tissue	Shell	Flesh	Ref.
MOLLUSCA							
Cephalopoda							
Octopus - Squid	1971-75	Tokai, Japan				1.6	Sr-34
Gastropoda							
Littorina littorea	<1966	Windscale area		5 - 17			Sr-48
Littorina littorea	1965-66	Windscale area		17			Sr-47
Limpits	1965-66	Windscale area		15			Sr-47
Pelecypoda							
Mytilus edulis	<1966	Windscale area		8			Sr-48
Mussel	1965-66	Windscale area		8			Sr-47
Short-neck clam	1965-67	Sea of Japan			114		Sr-33
Oyster	1965-67	Sea of Japan			84		Sr-33
Abalone	1965-67	Sea of Japan			111		Sr-33
Clam	1965-67	Sea of Japan			102		Sr-33
Mussel	1965-67	Sea of Japan			71		Sr-33
Shell fish	1971-75	Tokai, Japan				5.1	Sr-34
ARTHROPODA							
Crustacea							
Shrimp	1971-75	Tokai, Japan	28				Sr-34

Cobalt-60 Concentrations in Marine Fish from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{60}Co.

Co-1. (See Ref. Cs-1). Concentrations of ^{60}Co were determined in muscle tissue, liver and roe of four different species of Pacific salmon collected from Alaskan and Washington State coastal regions between July and September 1967. Concentrations in muscle ranged from 1.2 to 6.7 dpm/kg wet. CFs are reported using the total (soluble + particulate) concentration of ^{60}Co in the water.

2. Some additional references to fallout levels in Pacific fish; no reported CFs.

Co-2. Folsom, T.F., Young, D.R., Hodge, V.F., and Grinsmore, R., "Variations of ^{54}Mn, ^{60}Co, ^{65}Zn, ^{110m}Ag in Tunas," Radionuclides in Ecosystems, (Proc. Symp. Oak Ridge 1971) D. J. Nelson, Ed., United States Atomic Energy Commission, Washington, D.C., Conf-710501-II (1973), 721. Concentrations of ^{60}Co were determined in the liver of albacore caught near San Diego, CA, between 1964 and 1970, and in species from other oceanic regions. Between 1964 and 1970, ^{60}Co levels in albacore liver from San Diego ranged from 40 to 280 pCi/kg wet. The liver of yellowfin tuna from 1968 collections near San Diego contained from 20 to 40 pCi/kg wet. The concentrations of ^{60}Co in tuna liver collected in 1971 from the Marquesas Islands was from 6 to 15 pCi/kg wet; from northwest Africa in 1970, 1.2 to 3.1 pCi/kg wet; from the Pacific off Ecuador in 1971, 12 pCi/kg; and from the Hawaiian Islands in 1970, 25-68 pCi/kg wet. No accumulation factors are computed.

Co-3. (See Refs. Pu-4, Cs-15). ^{60}Co was measured in liver of albacore collected off San Diego, CA, during July and August between 1964 and 1971. Highest concentrations (174 pCi/kg wet) were found in samples collected during 1965. Concentrations fell off at a rate that gives an apparent half-residence time of about 2.5 years. The authors state that ^{60}Co has a shorter apparent half-time of residence in the upper layers of the Pacific than do ^{54}Mn, ^{65}Zn, ^{108m}Ag, ^{110m}Ag, ^{137}Cs and ^{239}Pu. No CFs are computed.

Co-4. Folsom, T.R., and Young, D.R., "Silver-110m and Colbalt-60 in Oceanic and Coastal Organisms," Nature 206, 803 (1965). ^{60}Co was measured in tissues of squid, mussels, barnacles and fish collected in 1964 from regions of the Pacific ocean. Concentrations in squid liver ranged from non-detectable levels to 3800 pCi/kg wet in samples collected west of the California current. Concentrations in byssal mussels and barnacles ranged from 10 to 40 pCi/kg wet. No CFs are reported.

Co-5. Pearcy, W.G., and Vanderploeg, H.A. "Radioecology of Benthic Fishes Off Oregon" Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle 1972), IAEA, Vienna (1973), 245. The authors note that ^{60}Co was detected in benthic fish from depths of 50-2800 m off the Oregon coast between 1964 and 1971. No data are provided.

Co-6. (See Refs. Cs-6, Cs-72). ^{60}Co, originating from waste discharged from the Humboldt Bay, CA, nuclear reactor, was below detection limits (less than 6 pCi/kg wet) in English sole collected from the bay during 1972 and 1973.

B. Central Pacific Atolls and Locations Possibly Affected by Local Fallout from the Pacific Nuclear Test Series

1. References containing field-derived CFs for ^{60}Co.

No reported values.

2. Some additional references to ^{60}Co concentrations in fish.

Co-7. (See Refs. Cs-23, Sr-11). ^{60}Co was measured in a variety of whole, eviscerated reef fish collected from islands of Bikini Atoll during 1969. Concentrations ranged from 0.13 pCi/g wet in goatfish from Eneu to 9.0 pCi/g wet in goatfish from Nam Island.

Co-8. (See Ref. Cs-24). During 1958, ^{57,58,60}Co were determined in flying fish and tuna from Enewetak Atoll. ^{60}Co was expressed as the percent of total radioactivity. In the white muscle of flying fish, ^{60}Co was 10% of the total activity while in tuna muscle its contribution was only 1-2% of the total activity.

Co-9. (See Refs. Cs-25, Cs-74, Sr-12). ^{60}Co concentrations in the muscle, liver and viscera of several species of fish collected from Bikini Atoll in May 1972 are reported. Highest levels of ^{60}Co were observed in the liver of dogtooth tuna taken from the waters of Bravo Crater (181 pCi/g dry). Goatfish taken near Nam Island exhibited similar levels in their viscera (170 pCi/g dry).

Co-10. (See Ref. Cs-26). ^{60}Co concentrations were determined in samples of liver, viscera and eviscerated whole fish collected during September 1976 from Rongelap Atoll. Concentrations in these parts ranged from 0.07 to 0.78 pCi/g dry.

Co-11. (See Refs. Cs-27, Pu-16, Cs-75, Sr-13, Sr-40). Concentrations of ^{60}Co are reported in various sections of different fish obtained from Rongelap, Utirik, Ailinginae and Rongerik Atolls in 1974 and from Bikini Atoll in December 1974 and April 1975. Levels in tissue of fish from Bikini (0.2 to 10 pCi/g dry) exceed the levels in fish from other atolls (0.03 to 0.9 pCi/g dry).

Co-12. (See Refs. Pu-18, Cs-29, Sr-10). ^{60}Co was above detection limits in some dissected fish parts from different species collected during a 1978 survey at atolls to the east of Enewetak-Bikini. Concentrations in the muscle tissue of different fish from Rongelap Atoll ranged from non-detectable levels to 36 pCi/kg wet weight.

Co-13. (See Refs. Pu-19, Cs-30). This report discusses the presence of ^{113m}Cd in marine organisms from Pacific Atolls but includes some concentrations of ^{60}Co in fish liver samples for comparative purposes. Concentrations in liver from the different fish ranged from non-detectable levels to 95 pCi/g dry wt.

Co-14. (See Refs. Pu-20, Cs-31). As in reference Co-13, the discussion centers on ^{113m}Cd concentrations but includes measurements of ^{60}Co in selected fish from Pacific atolls. Levels in muscle of fish from Enewetak ranged from 0.3 to 1.0 pCi/g dry.

Co-15. (See Refs. Pu-12, Pu-57, Cs-32, Sr-15, Sr-42). This is a summary and discussion of the results from a radiological survey of Enewetak Atoll conducted in 1972-1973. Concentrations of ^{60}Co are reported in tissue and organs from a

variety of reef and lagoon pelagic species. ^{60}Co was one of the dominant, man-produced radionuclides in goatfish. Concentrations in near-shore fish ranged fron non-detectable amounts to 400 pCi/g dry in viscera of butterfish. Most ^{60}Co levels were less than 5 pCi/g dry. No ^{60}Co was detected in fish from the control station, Kwajalein Atoll.

Co-16. (See Ref. Cs-34). ^{60}Co and ^{57}Co were measured in the light muscle of tuna collected between March and August 1962 from the vicinity of Christmas Island following the nuclear test series Dominic. Concentrations of ^{57}Co ranged from 0.02 - < 0.18 pCi/g wet and concentrations of ^{60}Co in the muscle ranged from 0.01 to 0.04 pCi/g. The highest concentration detected was 0.23 pCi/g wet.

Co-17. (See Ref. Cs-35). ^{60}Co was measured in different tissues of tuna landed at the Tokyo fish market between May and October 1962. Levels ranged from 0.9 pCi/g wet in the intestinal contents to non-detectable levels in the spleen and gonad. Concentrations in light and dark flesh ranged from 0.08 to 0.12 pCi/g wet.

Co-18. (See Refs. Pu-10, Pu-56, Cs-36, Cs-77, Sr-17, Sr-38). Comparative concentration ranges expressed as 10^{-6} μCi/g in tissues of fish collected between June 1956 and June 1957 from islands in the western Pacific were 1.6 to 753 for ^{57}Co, 0.2 to 19 for ^{58}Co, and 0.16 to 31 for ^{60}Co..

Co-19. (See Refs. Cs-37, Cs-78, Sr-39). ^{60}Co concentrations are reported in fish collected during a survey of Bikini and Enewetak in 1964. According to the authors ^{60}Co was the dominant radionuclide in fish tissues. Levels ranged from 2.9 to 56 pCi/g dry in entire fish from Bikini and from 5.9 to 46 pCi/g dry in entire fish from Enewetak. Species and islands sampled are identified.

Co-20. (See Refs. Pu-8, Cs-39, Cs-79, Sr-19). Average ^{60}Co levels in whole fish from Bikini and Enewetak Atolls during 1964 were 18 and 24 pCi/g dry, respectively. Fish liver samples contained from 40 to 540 pCi/g dry wt.

Co-21. (See Ref. Cs-14). Yellowfin tuna caught at Bikini Atoll in September 1969 contained small but measureable amounts of ^{60}Co in the dark muscle and liver. The average value in dark muscle was 1.0 pCi/g dry with a range of 0.08 to 4.6 pCi/g; the average value in liver was 1.3, with a range of 0.21 to 5.0 pCi/g.

Cobalt-60 in Marine Fish from Regions of the Atlantic and Indian Oceans and the Mediterranean Sea

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{60}Co.

No reported values.

Co-22. See Ref. Pu-43 for a review of stable Co accumulation factors.

2. Some additional references to ^{60}Co concentrations in Atlantic fish; no reported CFs.

Co-23. (See Refs. Cs-44, Cs-84, Sr-22, Sr-44). A variety of marine samples were collected during 1979 and 1980 from three regions of the NEA dumping site. The authors report finding 6 to 28 pCi/kg dry wt. of ^{60}Co in nektonic species collected from the regions. No CFs are reported.

Co-24. (See Ref. Cs-49). Fallout levels of ^{57}Co and ^{60}Cs were reported in the liver of marlin caught off the west coast of Puerto Rico in 1964. Concentrations ranged from 0.1 to 0.5 dpm/g wet weight. No CF are computed.

B. Coastal and Ocean Studies (Source term--Reprocessing Facilities)

1. References containing field-derived concentration factors for ^{60}Co in fish from both the immediate vicinity and at distances from Windscale releases.

No reported values.

2. Additional references to ^{60}Co concentrations in fish.

Co-25. (See Refs. Pu-45, Cs-59, Cs-89). ^{60}Co was reported below detection limits in fish collected between 1977-1980 from the vicinity of several coastal nuclear power stations in the British Isles.

Table 7. Reported concentration factors for ^{60}Co in fishes from regions of the world oceans and adjacent seas.

Common and/or scientific name	Year	Location	Muscle	Liver	Roe	Bone	Ref.
King Salmon	1967	Alaskan waters	9400	50000	42000		Co-1
Chum Salmon	1967	Alaskan waters	10000	32000	60000		Co-1
Sockeye Salmon	1967	Alaskan waters	4200	22000	28000	11000	Co-1
Silver Salmon	1967	Alaskan waters	5950	40000	25000		Co-1

Cobalt-60 Concentrations in Marine Invertebrates from Regions of the Pacific Ocean

A. Coastal and Ocean Studies (Source Term--Global Fallout, Reactor and Waste Disposal Site)

1. References containing field-derived concentration factors for ^{60}Co.

Co-26. Young, D.R., and Folsom. T.F. " Muscle and Barnacles as Indicators of the Variations of ^{54}Mn, ^{60}Co and ^{65}Zn in the Marine Environment" Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle, 1972) IAEA, Vienna (1973), 633. ^{60}Co was measured in samples of the oceanic gooseneck barnacle Lepas anatifera collected from the northeastern Pacific during 1964 and in Mytilus californianus, collected during 1963-1964 and 1971 from the northeast Pacific coast. ^{60}Co levels in Lepas collected from floating, anchored, and drifting substrates in the Pacific during 1964 ranged from 17 to 160 pCi/kg wet. In Mytilus californianus, at intertidal stations in California and Baja California, concentrations ranged from 3.0 to 3.5 pCi/kg wet. Enrichment factors on the order of 600 or greater were obtained for ^{60}Co in Mytilus and 1000 in Pollicipes polymerus (intertidal gooseneck barnacle).

Co-27. Harrison, F.L., "Accumulation and Loss of Colbalt and Cesium by the Marine Clam, Mya Arenuria, Under Laboratory and Field Conditions," Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle 1972) IAEA, Vienna (1973), 453. The accumulation of ^{60}Co and ^{137}Cs was followed for 174 days in clams introduced into a discharge canal receiving radioactive waste from the Humboldt Bay, CA, boiling water reactor. ^{137}Cs levels were too low

for accurate determination. The concentrations of ^{60}Co reached 100000-20000 pCi/kg in the peel and about 1000 pCi/kg in the body (peel removed). The value of the concentration factor is approximately 500 for the body with peel removed.

Co-28. (See Ref. Cs-69). The CF determined for ^{60}Co in soft parts of oysters maintained in the discharge canal of the Humboldt Bay nuclear reactor was 6000. Concentrations varied with releases and tidal cycles. Between June 1971 and January 1973, concentrations in soft tissue ranged from 20 to 2000 pCi/kg.

2. Some additional references to ^{60}Co concentrations in invertebrates.

Co-29. (See Ref. Cs-11). ^{60}Co and ^{58}Co concentrations are reported in sea hare (Aplysia californica) caught locally from the region of the San Onofre nuclear power station during 1970, 1971 and 1972. Concentrations of ^{60}Co in the mollusk ranged from 7 to 85 pCi/kg wet weight and ^{58}Co levels were between 12 and 2260 pCi/kg during this period. No CFs were computed.

Co-30. (See Refs. Co-6, Cs-6, Cs-72). ^{60}Co was below detection limits in monthly collections of clams, oysters, and crabs for Humboldt Bay, CA, during 1972-1973.

B. Central Pacific Atolls and Locations Possibly Affected by Local Fallout from the Pacific Nuclear Test Series

1. References containing field-derived concentration factors for ^{60}Co.

No reported values.

2. Additional references to ^{60}Co concentrations in invertebrates from Pacific atolls.

Co-31. (See Refs. Pu-11, Cs-39, Cs-79, Sr-19, Co-20). Average levels of ^{60}Co in sea invertebrates collected during 1964 from Enewetak and Bikini were 170 and 100 pCi/g dry weight. ^{57}Co was also detected in the samples analyzed during this period.

Co-32. (See Refs. Co-19, Cs-37, Cs-78, Sr-39). Co^{57} and Co^{60} were detected in a number of marine invertebrates collected during August 1964 from Enewetak and Bikini Atolls. Kidneys of clams had concentrations of ^{60}Co in excess of 1000 pCi/g. Concentrations in clams and sea cucumbers from Bikini were higher than the levels in samples from Enewetak.

Co-33. (See Refs. Co-18, Pu-10, Pu-56, Cs-36, Cs-77, Sr-17, Sr-38). ^{57}Co, ^{58}Co and ^{60}Co were detected in clams and invertebrates collected between June 1956 and June 1957 from islands in the western Pacific. Comparative concentration ranges in units of 10^{-6} µc/g were as follows: ^{57}Co, 1.6 to 753; ^{58}Co, 0.2 to 19; ^{60}Co, 0.16 to 37.

Co-34. (See Refs. Co-15, Pu-12, Pu-57, Cs-32, Sr-15, Sr-42). This is a summary and discussion of the results from a radiological survey of Enewetak Atoll conducted in 1972-1973. ^{60}Co concentrations are reported in tissues of Tridacana clams, spiny lobster, pencil urchins and top snails from different islands of the atoll. ^{60}Co was the most abundant radionuclide accumulated by the Tridacna clam with highest concentrations noted in the kidney. Levels in the kidney ranged from 280 to 2100 pCi/g dry wt., and levels were lower and decreasing in viscera, mantle, and muscle tissues in that order.

Co-35. (See Refs. Co-10, Cs-26). ^{60}Co was measured in tissues of Tridacna clams collected during September 1976 at Rongelap Atoll. Kidneys contained from 7.6 to 16 pCi/g.

Co-36. (See Refs. Cs-25, Cs-74, Sr-12, Co-9). ^{60}Co was measured in tissues of spiny lobsters collected during May 1972 from Bikini and Eneu Islands, Bikini Atoll. Concentrations in muscle tissue ranged from 0.05 to 0.23 pCi/g dry.

Co-37. (See Refs. Cs-80, Sr-41). Average ^{60}Co concentrations are provided from the muscle and mantle of giant clams collected during the 1978 survey of several northern Marshall atolls. Concentrations ranged from less than 1 to 17 pCi/kg wet wg; no CFs are reported.

Co-38. (See Refs. Co-38, Co-22). ^{60}Co and ^{57}Co were detected in spider snails, spiny lobsters and Tridacna from Guam, and in Tridacna clams from Palau following the Hardtack nuclear test series in 1958. The highest level of ^{57}Co was found in the kidney of Tridacna from Guam.

Co-39. Weiss, H.V., and Shipman, W.H., "Biological Concentration by Killer Clams of Colbalt-60 from Radioactive Fallout", Science 125, 695 (1957). First report on ^{60}Co in soft tissues of Tridacna clams following nuclear test in 1954. Samples were obtained from Rongelap Atoll. Concentrations in total soft tissue were 2.1 to 7.1 x 10^5dpm.

Co-40. (See Refs. Pu-16, Cs-27, Cs-75, Sr-13, Sr-40, Co-11). ^{60}Co levels are reported in tissues of Tridacna clams collected during 1974 and 1975 from Bikini, Rongelap and Utirik Atolls. Concentrations were highest in specimens from Bikini. The concentration of ^{60}Co in clam muscle was 5 pCi/g dry.

Cobalt-60 Concentrations in Marine Invertebrates from Regions of the Atlantic and Indian Oceans and the Mediterranean

A. Coastal and Ocean Studies (Source--Global Fallout, Reactor and Waste Disposal Sites)

1. References containing field-derived concentration factors for ^{60}Co.

   No reported values.

2. Some additional references to concentrations of ^{60}Co accumulated by Atlantic invertebrates.

Co-41. (See Refs. Co-23, Cs-44, Cs-84, Sr-22, Sr-24). The concentration of ^{60}Co was determined in a variety of benthic organisms including cuttlefish, crustacea, sea anemones, sea stars and sea cucumbers collected from the northeast Atlantic during 1979 and 1980. ^{60}Co concentrations in benthic organisms ranged from 17 to 1100 pCi/kg dry wt; no CFs were computed.

B. Coastal and Ocean Studies (Source Term--Reprocessing Facilities Discharges)

1. References containing field-derived concentration factors for ^{60}Co in invertebrates from both the immediate vicinity and at distances from Windscale releases.

   No reported values.

2. Additional references to ^{60}Co concentrations in invertebrates from the immediate vicinity and at distances from Windscale discharges.

Co-42. (See Refs. Co-25, Pu-45, Cs-59, Cs-89). ^{60}Co levels are reported in several invertebrates from the Windscale shoreline area and other areas of the Irish Sea. Samples were collected between 1977 and 1980. Concentrations ranged from 1.2 pCi/g in winkles from the Windscale shore line to 0.03 pCi/g at Clyde during 1977.

Co-43. (See Refs. Cs-62, Cs-90). This series of reports includes yearly data for ^{60}Co in different invertebrates collected from regions of the British Isles and other nearby vicinities during the period 1966-1976.

3. References containing field-derived concentration factors for ^{60}Co in invertebrates from the vicinity of the Bhabha Atomic Research Center, Bombay, India.

No reported values.

4. Additional references to ^{60}Co concentrations in invertebrates from the vicinity of Bombay, India.

Co-44. (See Refs. Cs-97, Sr-51). ^{60}Co was measured in sea food samples (prawns, crabs, oysters, clams, lobsters, onchedium and nerita species) collected from the Tarapur, India coastal environment between 1975 to 1979. Concentrations ranged from 1 to 5 Bq/kg in soft tissue; no CFs are computed. No ^{60}Co was detected in coastal seafood organisms beyond 10 km of the TAPS site.

Table 8. Reported concentration factors for ^{60}Co in invertebrates from regions of the world oceans.

Common and/or scientific name	Year	Location	Soft tissue	Ref.
MOLLUSCA				
Pelecypoda				
Mytilus californianus	1963-64	Pacific coast, U.S.	600	Co-26
Clam, Mya arenaria	1973	California coast	500	Co-27
Oyster, Crassostrea gigas	1971-73	Humboldt Bay, CA	6000	Co-28
ARTHROPODA				
Crustacea				
Barnacle	1963-64	Pacific coast, U.S.	1000	Co-26

Concentrations of the Natural Radionuclides (Polonium to Uranium) in Marine Fish from Regions of the World Oceans

1. References containing field-derived concentration factors.

Po-Ra-Th-U-1. Cherry, R.D., and Shannon, L.V., "The Alpha Radioactivity of Marine Organisms", Atom. Energy Rev., 12, 1 (1974). This paper provides a review of the literature prior to 1973 dealing with uranium, thorium, radium and polonium isotopes accumulated by marine organisms. Summary tables of typical concentrations and concentration factors are provided. The later values are abstracted and shown in the tables accompanying this section.

Po-2. Folsom, T.R., Wong, K.M., and Hodge, V.F., "Some Extreme Accumulations of Natural Polonium Radioactivity Observed in Certain Oceanic Organisms", The Natural Radiation Environment II, J.A.S. Adams, W.M. Lowder and T.F. Gesell (Eds.), Conf.-72085-P2. U.S. Energy Research & Development Administration, Oak Ridge, Tenn., (1975) 863-882. Concentrations of ^{210}Po were determined in organs and tissues of lanternfish, sable fish, tuna, and albacore collected from California coastal waters. Concentrations as high as 79000 pCi/kg were detected in

certain lobes of large organs in albacore. Some of the reported concentration factors are abstracted and shown in the tables accompaning this section.

Po-3. (See Ref. Pu-7). Concentrations of ^{210}Po are reported in sections of different fish from Bikini and Enewetak Atolls. Concentration factors are also computed and range from 10^2 to 10^4 for the tissues analyzed.

Po-Pb-4. Heyrand, M., and Cherry, R.D., "Polonium-210 and Lead-210 in Marine Food Chains," Marine Biol. 52, 227 (1979). ^{210}Po and ^{210}Pb were measured in several tissues and organs of tuna collected off Monaco. Concentration factors were computed using water concentrations provided in the report.

Po-Pb-5. Beasley, T.M., Eagle, R.J., and Jokela, T.A., "Polonium-210, Lead-210 and Stable Lead in Marine Organisms." United States Atomic Energy Commission, Health and Safety Laboratory, New York, NY, HASL-273, (1973) 2-36. An extensive array of ^{210}Pb and ^{210}Pb concentrations are provided for tissues and organs from a variety of fish collected from the North Pacific between 1969-1970. Variability between trophic levels can be pronounced and organisms from within trophic levels show seasonal changes in their ^{210}Po concentration. ^{210}Po concentrations are amplified through successive food chains while ^{210}Pb does not show this trend. Concentration factors are computed using water concentrations reported in this paper.

Ra-6. (See Refs. Cs-1, Co-1). Concentrations of ^{226}Ra were determined in tissues of different species of Pacific salmon collected from Alaskan and Washington coastal regions between July and September 1967. Concentrations in muscle ranged from 5 to 105 dpm/kg wet weight. CFs are reported.

2. Some additional references; no reported concentration factors.

Po-7. Folsom, T.R., and Beasley, T.M., "Contributions from the Alpha Emitter, Polonium-210, to the Natural Radiation Environment of the Marine Organisms", Radioactive Contamination of the Marine Environment (Proc. Symp. Seattle 1972) IAEA, Vienna, (1973), 625. ^{210}Po was determined in a variety of surface and deep sea marine organisms collected off the

southern California and Oregon coasts between 1965-1968. Levels in albacore muscle were 300 dpm/kg wet and in lanternfish concentrations ranged from 460 to 7030 dpm/kg wet. ^{210}Pb concentrations were also measured in lanternfish collected from the north Pacific during 1950-1951. Concentrations ranged from 45 to 220 dpm/g wet.

Po-8. Pentreath, R.J., "Biological Studies" Interim Oceanographic Description of the North-East Atlantic Site for the Disposal of Low-Level Radioactive Waste, P. A. Gurbutt and R. R. Dickson, Eds., OCDE/OECD, Nuclear Energy Agency Publication,(1983), 101. A number of fish caught near the sea bed from areas off the north coast of the Atlantic were analyzed for ^{210}Po. Concentrations in muscle, liver, and gonad tissue showed no consistent change with increasing depth. No CFs are reported.

Po-9. Cherry, R.D., and Heyraud, M., "Evidence of High Natural Radiation Doses in Certain Mid-Water Oceanic Organisms", Science **218**, 54 (1982). ^{210}Po concentrations are reported in several crustaceans and fish from depths to 1500 m, and in a few deep benthic crustaceans. The data indicate that certain categories of mid-water fish contain consistently higher levels of ^{210}Po than previously reported. These levels ranged from 3 to 74 pCi/dry g in Melamphaeidae.

Po-10. Hoffman, F.L., Hodge, V.F., and Folsom, T.R., "Polonium Radioactivity in Certain Mid-Water Fish of the Eastern Temporal Pacific", Health Phys. 26, 65 (1974). ^{210}Po activities of nine food organisms of tunas were determined. The average concentration in the food organisms (2.1 pCi/g wet) was essentially the same as the whole body concentration (1.5 pCi/g wet) observed in albacore. They suggest that polonium comes to the fish via its food and is concentrated in visceral parts during the digestive process. No increase in concentration was noted as a function of trophic level. No CFs were computed.

Po-11. (See Ref. Pu-43). This paper is a review of natural and man-made radionuclides in fish abstracted from the literature prior to 1976. No CFs are provided but a comprehensive discussion of the available data on natural radionuclides in fish is provided.

Po-12. Hoffman, F.L., Hodge, V.F., and Folsom, T.R., "^{210}Po Radioactivity in Organs of Selected Tunas and Other Marine Fish", J. Radiat. Res. 15, 103 (1974). ^{210}Po was determined in organs of 10 oceanic fish from three families. The highest activities were consistently found in the pyloric caecal masses or intestinal contents of these fish. Muscle concentrations ranged from 0.01 to 1.3 pCi/g wet.

Po-Pb-13. Schell, W.R., Jokela, T., and Eagle, R., "Natural ^{210}Pb and ^{210}Po in a Marine Environment" Radioactive Contamination of the Marine Envir. (Proc. Symp. Seattle 1972) IAEA, Vienna (1973), 701. ^{210}Pb and ^{210}Po were measured in several marine species collected during the period 1970-1971 from the northeast Pacific. Concentrations of ^{210}Po in herring and smelt ranged from 0.20 to 4.8 pCi/g wet and levels of ^{210}Pb ranged from 0.007 to 0.17 dpm/g wet. In chinook salmon, ^{210}Po levels were between 0.03 to 24.5 dpm/g wet; in starry flounder the range was from 0.14 to 1.4 dpm/g wet; in hake the levels ranged from 0.05 to 3.6 dpm/g wet; in sable fish levels were between 0.3 and 103 dpm/g wet; in whiting levels ranged from 0.5 to 2.9 dpm/g wet; in rat-tail the levels were from 0.3 to 16.0 dpm/g wet.

Po-Pb-14. Higgo, J.J.W., and Cherry, R.D., "Plutonium and other Alpha Radioactive Isotopes in Marine Organisms in the Southern Hemisphere", U.S. Dept. of Energy, Environmental Measurements Laboratory, New York, NY, EML-342, (1978), I-23. ^{210}Po and ^{210}Pb concentrations are reported for the pyloric caecum, liver, stomach contents and wall of tuna collected from the vicinity of Cape Town in 1973. No CFs are reported.

Po-Pb-15. Beasley, T.M., Jokela, T.A., and Eagle, R.J., "Radionuclides and Selected Trace Elements in Marine Protein Concentrates", Health Phys. 21, 815 (1971). ^{210}Po and ^{210}Pb concentrations were determined in tissues of pelagic fish from Oregon and California coastal areas in 1969. Concentrations of 0.07 to 0.74 and 0.2 to 5.7 dpm/g dry of ^{210}Po and ^{210}Pb, respectively, were also measured in selected samples of fish protein concentrates from various locations.

Po-Pb-Ra-16. Holtzman, R.B., "Concentrations of the Naturally Occurring Radionuclides ^{226}Ra, ^{210}Pb and ^{210}Po in Aquatic Fauna", Symp. Radioecology, D.J. Nelson and F.C. Evans, Eds., United States Atomic Energy Commission Washington, D.C., Conf. 670503 (1969), 535. The concentrations of ^{226}Ra, ^{210}Pb and ^{210}Po were determined in hard and soft tissue of marine fish, shellfish, seals and whales and in some dietary components of whales. ^{226}Ra concentrations were independent of the species at about 5 pCi/100g bone ash and 0.2 pCi/100 g wet soft tissue. Both ^{210}Po and ^{210}Pb levels were greater than ^{226}Ra. In bone from fish and seal the ^{210}Pb and ^{210}Po were about 15 pCi/100 g ash. Fish muscle contained about 0.2 pCi ^{210}Pb/100g wet and about 10 times as much ^{210}Po.

Po-U-17 Pentreath, R.J., Woodhead, D.S., Harvey, B.R., and Ibbett, R.D., "A Preliminary Assessment of Some Naturally-Occurring Radionuclides in Marine Organisms (Including Deep Sea Fish) and the Absorbed Dose Resulting From Them", Marine Radioecology (Proc. 3rd NEA Sem., Tokyo 1979) OECD, Paris (1980), 291. Results of internal accumulation of several natural radionuclides, and particularly of ^{210}Po, are shown for a number of coastal water, deep sea fish and a deep sea amphipod. Concentrations of ^{238}U in bone samples of European coastal and shallow water fish ranged from 1.6 to 80 fCi/g. The mean levels of ^{210}Po in muscle, liver and bone of pelagic and demersal teleosts were 62 and 28 fCi/g; 2490 and 1670 fCi/g; and 45 and 87 fCi/g respectively. Concentrations of ^{210}Po in muscle of fish caught at depths of 500 to 1250 meter ranged from 5.5 to 61 fCi/g. Concentrations of ^{210}Po in the liver, bone, gonad and cartilage of these fish are also given.

Po-Th-U-18 (See Ref. Pu-42). Concentrations of ^{238}U in bone of plaice ($x = 13.9\ ngg^{-1}$), mackerel ($x=135\ ngg^{-1}$) and cod ($x = 8.6\ ngg^{-1}$) and ^{210}Po in the liver, muscle and bone from these fish are reported. ^{238}U was not detected in muscle tissue at concentrations greater than $1\ ngg^{-1}$ wet. Analyses for ^{232}Th also resulted in negative results. It was not present in concentrations greater than $5\ ngg^{-1}$ wet in bone and not greater than $0.5\ ngg^{-1}$ wet in muscle.

Table 9. Reported concentration factors for several natural radionuclides (polonium to uranium) in fish from regions of the world oceans.

Radionuclide	Common and/or scientific name	Year	Location	Total animal	Muscle	Bone	Liver	Ref.
^{210}Po	Not provided	Unk.	--	1.6×10^4	2×10^3	4×10^3	3×10^3	Po-Ra-Th-U-I
	Tuna, Thunnus alalunga	1972	Pacific		5×10^3		3×10^5	Po-2
	Lantern fish, Tarletonbeania crenularis	1972	Pacific	2×10^5				Po-2
	Skipjack tuna	1972	Enewetak Atoll		3.9×10^4			Po-3
	Convict surgeon	1972	Bikini Atoll		4.1×10^3		8.6×10^4	Po-3
	Tuna, Thunnus thynnus	Unk.	Monaco		[a]3.2×10^3		[a]1.1×10^5	Po-Pb-4
	Pelagic fish (III Trophic level)	1969	Pacific	[a]3.6×10^3				Po-Pb-5
	Pelagic fish (III-V Tropic level)	1969	Pacific	[a]8.9×10^3				Po-Pb-5
	Demersal fish - Whiting	1969	Pacific	[a]2.8×10^4				Po-Pb-5
	Demersal fish - Sablefish	1969	Pacific	[a]4.2×10^3				Po-Pb-5
	Demersal fish - Flatfish	1969	Pacific	[a]4.2×10^3				Po-Pb-5
	Demersal fish - Hake	1969	Pacific	[a]2.8×10^3				Po-Pb-5
^{210}Pb	Thunnus thynnus	Unk.	Monaco				[a]370	Po-Pb-4
	Pelagic fish (III Trophic level)	1969	Pacific	[a]420				Po-Pb-5
	Pelagic fish (III-V Trophic level)	1969	Pacific	[a]150				Po-Pb-5
	Demersal fish - Whiting	1969	Pacific	[a]67				Po-Pb-5
	Demersal fish - Sablefish	1969	Pacific	[a]420				Po-Pb-5
	Demersal fish - Flatfish	1969	Pacific	[a]150				Po-Pb-5
	Demersal fish - Hake	1969	Pacific	[a]150				Po-Pb-5
^{226}Ra	Not provided	Unk.	--	83	50	330		Po-Ra-Th-U-I
	Chum Salmon	1967	N. Pacific		750			Ra-I
	Silver Salmon	1967	N. Pacific		210			Ra-I
^{228}Th	Not provided	Unk.	--	1.3×10^3	600			Po-Ra-Th-U-I
^{238}U	Not provided	Unk.	--		6×10^{-2}			Po-Ra-Th-U-I

[a] Computed from water concentrations provided in the respective reports.

Concentrations of the Natural Radionuclides (Polonium to Uranium) in Marine Invertebrates from Regions of the World Oceans

1. References containing field-derived concentration factors.

Po-19. (See Ref. Po-2). Concentrations of ^{210}Po are reported in a variety of tissues from several marine invertebrates collected from California coastal waters in 1972. CFs are reported.

Po-20. (See Ref. Pu-65). Concentrations of ^{232}Th, ^{210}Pb and ^{210}Po were determined in the branchial hearts, hepatopancreas, remainer, and in the reconstituted Octopus vulgaris collected in the littoral zone off Monaco. Concentrations in the hepatopancreas were highest at 5.85×10^5 mBq/kg wet. CF values are provided.

Po-21. (See Ref. Po-Pb-4). ^{210}Pb and ^{210}Po concentrations were determined in whole animal, muscle and hepatopancreas of crustaceans and of molluscan cephalopods representative of a pelagic and benthic food chain. The concentration factors from seawater to whole animals were approximately constant along both food chains, being of the order of 10^4 for ^{210}Po and 10^2 for ^{210}Pb.

Po-Pb-22 Cherry, R.D., Heyrand, M., and Higgo, J.J.W., "Polonium-210: its relative enrichment in the hepatopancreas of Marine Invertebrates", Mar. Ecol. Prog. Series 13, 229 (1983). Typical concentration factors for ^{210}Po and ^{210}Pb in the hepatopancreas from mollusks (gastropods, lamellibranchs and cephalopods) and from crustaceans are 6×10^5 and 3×10^3 respectively.

2. Some additional references; no reported concentration factors.

Po-23. (See Ref. Po-7). Concentrations of ^{210}Po were measured in several invertebrates collected off the Oregon coast in 1968. Highest levels were found in polychaete worms (1788 dpm/kg wet). Sea cucumbers from the area contained 810 dpm/kg wet.

Po-24. (See Ref. Po-9). Concentrations of ^{210}Po are reported in mid-water crustaceans collected at depths ranging to 1500 m from regions of the Atlantic Ocean. Mid-water shrimp are significantly higher in ^{210}Po than are those from surface waters.

Po-25. Heyrand, M., Fowler, S.W., Beasley, T.M., and Cherry, R.D., "Polonium-210 in Euphausiids: A Detailed Study", Mar. Biol. 34, 127 (1976). This report is a detailed study of ^{210}Po concentrations in the euphausiid Meganyctiphanes norvegica. The distribution of ^{210}Po in the animal was not homogeneous. The majority of the activity is concentrated in the internal organs, the alimentary tract and the hepatopancreas in particular.

Po-Ra-Th-U-26 (See Ref. Po-Ra-Th-U-1). Typical levels of the alpha emitting radionuclides ^{228}Th, ^{226}Ra, ^{210}Po and ^{238}Pu are summarized from the literature published prior to 1973. Concentrations (pCi/kg wet) in marine shells are: ^{238}U-30; ^{228}Th-1; ^{226}Ra-50 and ^{210}Po-300. In mollusca soft tissues the typical concentrations are reported as ^{228}Th-10; ^{226}Ra-20 and ^{210}Po-500.

Po-Pb-27 Cherry, R.D., and Heyrund, M., "Polonium-210 Content of Marine Shrimp: Variation with Biological and Environmental Factors", Marine Biology 65, 165 (1981). Concentrations of ^{210}Po and ^{210}Pb are reported in more than 30 species of marine shrimp collected between 1977 and 1980 from the Mediterranean near Monaco, Kuwait, South Africa, USA and Great Britian. The median concentration was 8.0 pCi/g dry wt. in the whole shrimp and 85 pCi/g dry in the hepatopancreas; the corresponding ^{210}Po:^{210}Pb activity ratios were 77 and 138, respectively. CFs are not reported.

Po-Pb-28 (See Ref. Po-Pb-13). ^{210}Po and ^{210}Pb concentrations were determined in intertidal organisms collected during 1971 from the northeast Pacific. Levels of ^{210}Pb in barnacles ranged from 0.02 to 0.53 dpm/g wet and ^{210}Pb concentrations ranged from 05 to 0.13 dpm/g wet. Concentrations of ^{210}Po in oysters ranged from 0.3 to 4.4 dpm/g wet and ^{210}Pb levels ranged from 0.01 to 0.2 dpm/g wet. No CFs are computed.

Po-Pb-29 (See Ref Po-Pb-14). Concentrations of ^{210}Po, ^{210}Pb, ^{226}Ra, $^{228, 230, 232}Th$ and $^{234, 238}U$ were determined in a variety of invertebrates collected from the vicinity of Cape Town. No distinct, inter-element relationships emerged from these collateral determinations.

Po-Pb-30 Bennett, J. T., and Carpenter, R. "Concentrations and Temporal Variations of ^{210}Po, ^{210}Pb, and Al in the Surf Zone Ecosystem of Copalis Beach, Washington", Estua. Coast. Mar. Sci.8, 127 (1979). ^{210}Po and ^{210}Pb are reported in selected benthic organisms collected between 1975-1976 from Copalis Beach, WA. Meio- and macro-benthic infauna from the beach exhibited a wide range of ^{210}Pb and ^{210}Po concentrations. Food chain magnification of these radionuclides by the benthic was not observed. No CFs were computed.

Po-Pb-31 (See Ref. Po-Pb-5). ^{210}Pb and ^{210}Po concentrations are reported in a variety of marine invertebrates collected from the northeast Pacific in 1969 and 1970. The data is too extensive to summarize briefly. The authors conclude there is pronounced variability in concentrations among trophic levels, and organisms from lower trophic levels show seasonal changes in their ^{210}Po concentrations.

Ra-32 (See Ref. Cs-44). The following mean concentrations were determined in a variety of nektonic and benthic organisms collected from the northeast Atlantic in 1979 (pCi/kg dry):

	Nekton	Benthic
^{226}Ra	1400	1500
^{228}Ac	170	200
^{234m}Pa	6100	1000
^{234}Th	3600	1100

Po-U-33 (See Ref. Pu-54). ^{238}U levels in byssal threads and ^{210}Po concentrations in tissues and shells of mussels collected from coastal sites of the U.S. are provided. Po concentrates in the soft tissue, with a small variation in the ratio of lead in the shell to lead in the tissue were measured at 0.07 : 0.16.

U-34 Hamilton, E.I., "Concentration and Distribution of Uranium in Mytilus edulis and Associated Material", Mar. Ecol. Prog. Ser. 2, 61 (1980). Concentration and distribution of uranium in the mussel Mytilus edulis are described for sampling sites in the United Kingdom near and distant from sources of nuclear effluents. With the exception of uranium associated with food, and particulate material present in the digestive organ the highest levels were found associated with byssal threads, the periostracum, and the excretory organs. No CFs are reported.

Table 10. Reported concentration factors for several natural radionuclides (polonium to uranium) in invertebrates.

	Common and/or scientific name	Location	Whole animal	Soft tissue	Shell	Hepato-pancreas	Ref.
	MOLLUSCA						
^{210}Po	Cephalopoda						
	Loligo vulgaris	Mediterranean	3×10^4				Po-21
	Octopus vulgaris	Mediterranean	0.9×10^4				Po-21
	Eledone aldrovandii	Mediterranean	1×10^4				Po-21
	Sepia officinalis	Mediterranean	3×10^4				Po-21
	Octopus vulgaris	Mediterranean	2×10^4				Po-21
	30 species of molluscans and crustaceans	Unknown				5×10^5	Po-20
^{210}Pb	Loligo vulgaris	Mediterranean	3×10^2			6×10^3	Po-Pb-22
	Octopus vulgaris	Mediterranean	5×10^2				Po-21
	Eledone aldrovandii	Mediterranean	$>2 \times 10^2$				Po-21
	Sepia officinalis	Mediterranean	13×10^2				Po-21
	30 species of molluskas and crustaceans	Unknown					Po-21
^{232}Th	Octopus vulgaris	Mediterranean	90			3×10^3	Po-Pb-22
^{210}Po	Pelecypoda					400	Po-20
	Red Abalone, Haliotis rufesceu	Calif. coast		1×10^3			Po-19
	Clam, Tresus vittallii	Calif. coast		3×10^4	1.8×10^5		Po-19
	ARTHROPODA						
	Crustacea						
	Meganyetiphanes norvegica	Mediterranean	0.8×10^4				Po-21
	Sergestes articus	Mediterranean	15×10^4				Po-21
	Sergestes sp.	Mediterranean	15×10^4				Po-21
	Pasiphaea sivado	Mediterranean	1×10^4				Po-21
	Lysmata seticaudata	Mediterranean	7×10^4				Po-21
	Palaemone serratus	Mediterranean	5×10^4				Po-21
	Carcinus maenas	Mediterranean	2×10^4				Po-21
	Barnacle, Lepas pectinata	Calif. coast		2.2×10^5	1×10^4		Po-21
^{210}Pb	Meganyetiphanes norvegica	Mediterranean	5×10^2				Po-19
	Sergestes articus	Mediterranean	23×10^2				Po-21
	Sergestes sp.	Mediterranean	6×10^2				Po-21
	Pasiphaea sivado	Mediterranean	2×10^2				Po-21
	Lysmata seticaudata	Mediterranean	$>8 \times 10^2$				Po-21
	Palaemone serratus	Mediterranean	$>4 \times 10^2$				Po-21
	Carcinus maenas	Mediterranean	14×10^2				Po-21